WATER QUALITY OF SELECTED TAILWATERS

by

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This report presents field and analytical techniques for studying the mechanisms and chemical transformations occurring in reservoir tailwaters. The research focuses on the poor water quality associated with deep, anoxic releases from hydropower and non-hydropower reservoirs. Water quality results from the tailwaters of the Little Missouri River (Lake Greeson), Fouche La Fave River (Nimrod Lake), Rough River (Rough River Lake), and Guadalupe River (Canyon Lake) are presented and discussed.

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Anoxic water	pH
Canyon Dam	Reduced iron
Dissolved oxygen depletion	Reduced manganese
Five-day BOD	Reduced sulfides
Fourche La Fave River	Reservoir
Greeson Dam	Rough River
Guadalupe River	Rough River Dam
Iron-manganese-sulfide oxidation rates	Sulfate
Little Missouri River	Steady-state sample
Metals	Tailwater
Nimrod Dam	Ten-day BOD
Nitrogen	Time-of-travel sample
Organic carbon	

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles	2.589998	square kilometres

WATER QUALITY OF SELECTED TAILWATERS

PART I: INTRODUCTION

1. Reservoir tailwaters are a valuable component of the total reservoir project. Not only do they provide such beneficial uses as recreation and water supply, but they also support important fisheries. Often, many US Army Corps of Engineers reservoirs release anoxic waters high in reduced substances into tailwaters. This can be hazardous to aquatic life, cause water treatment problems, and affect areas used for recreation. Eventually the water quality will recover to baseline conditions; however, the chemical and recovery mechanisms of the tailwater must be better understood to practice effective water quality management. Thus, the goals of the work discussed herein were to develop an improved understanding of chemical transformations and recovery mechanisms in selected Corps reservoir tailwaters and to provide guidance on sampling and analysis of tailwater quality.

2. Dissolved oxygen depletion and subsequent development of low redox potentials in the deeper portion of stratified reservoirs have been documented by numerous investigators (Gunnison and Brannon 1981; Ingols 1957; Bella 1970; and Kennedy and Nix 1986). In some reservoirs it is common for the redox potential to drop to levels where reduced forms of iron, manganese, sulfur, and nitrogen are formed in the water column or they form in bottom mud followed by migration throughout the anoxic water column (Nix 1986). When water is released from elevations in a stratified reservoir where these reduced chemical species are present, the water quality of the receiving stream (tailwater) can be significantly impacted (Walburg et al. 1981). In most cases the releases from a reservoir constitute the entire flow of the immediate tailwater.

3. When anoxic water is released from a non-hydropower dam, substantial reaeration is often induced by the release structure (Wilhelms, Schneider, and Howington 1987). The dissolved oxygen concentration immediately downstream from the point of release will vary depending on such factors as temperature and turbulence. However, structural aeration is usually very limited for releases through hydropower facilities (Bohac et al. 1983).

4. The introduction of oxygen into the tailwater initiates oxidation reactions which alter the concentration of certain chemical components. The

dissolved oxygen concentration of the tailwater depends on the rate at which oxygen-consuming reactions occur as well as the rate at which oxygen is introduced into the system. As soon as the anoxic water is aerated, numerous chemical species begin to exert their demand on dissolved oxygen, and reduced substances begin to oxidize (Stumm and Morgan 1970). The water quality improves as the reactions take place and the water moves downstream. Eventually, water quality approaches conditions of the natural stream.

5. Effective water quality management of reservoir tailwaters requires an improved understanding of the physicochemical processes and better techniques for assessing tailwater quality. Assessment may involve measurement of existing conditions and/or prediction of future conditions resulting from structural or operational modifications of the reservoir tailwater system. Mathematical modeling of the various oxygen consumption processes is an integral part of predicting downstream dissolved oxygen concentrations. Improvement of these modeling techniques and development of new approaches for predicting the fate of reduced-chemical substances of these systems rely on an understanding of the major processes occurring in the tailwater.

6. Some water quality data are available from tailwaters but systematic investigations of the tailwater in the section of the stream which is affected by the releases from dams are relatively rare. Gordon's review of the chemistry of tailwaters (Gordon and Bonner 1983) is quite comprehensive but it reveals that few studies provide all of the data needed to conduct model evaluation and development. Gordon's work on the Duck River below Normandy Dam has provided some information on the rates of some of the oxygen-consuming reactions (Gordon 1989).

7. In order to evaluate models and to develop new approaches applicable to the modeling of tailwater systems, it is necessary to obtain detailed water quality data on selected tailwaters. The Environmental Laboratory of the US Army Engineer Waterways Experiment Station (WES) studied tailwaters of a variety of Corps projects to get a better understanding of the processes occurring in these tailwaters. During the summer and fall of 1987, studies were initiated on the Little Missouri River downstream from Narrows Dam in southwestern Arkansas. This site was chosen because of experience gained during a previous study by Nix (1986) which looked at similar constituents in the tailwater. Also, it was within driving distance from the contractor's facilities and met other study needs such as hypolimnetic releases of anoxic water and hydropower generation. The initial phase of the study focused on

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sampling and analytical protocol which would be required to obtain the needed data. Although dissolved oxygen depletion had been observed to occur in the hypolimnion of Lake Greeson in previous years, anoxic conditions did not develop to the extent needed to produce high concentrations of reduced chemical species during the fall of 1987. For this reason, only moderate loading of reduced chemical species occurred in the Little Missouri River below Narrows Dam during the study period. Even with decreased loading of reduced chemical species, this tailwater study provided an opportunity to develop the sampling and analytical methodology needed to obtain the necessary data.

8. Following the basic procedures established in the Greeson tailwater study, three additional tailwaters were studied during the summer and fall of 1988. These reservoirs were Lake Nimrod in west central Arkansas, Rough River Lake in western Kentucky, and Canyon Reservoir in central Texas. Lake Nimrod was chosen as a study site because, like Lake Greeson, it was close to the contractor's facilities. In addition, it has hypolimnetic releases of anoxic water and is a non-hydropower dam. The Rough River Lake site was chosen because of its more northerly latitude as compared to Lakes Greeson and Nimrod. It also met other criteria of hypolimnetic, nonhydropower releases. One feature that made Rough River Lake an interesting site to study was the pooled reach created by a small run-of-the-river dam used for hydropower in earlier days. Canyon Reservoir was chosen as the last study site because of the more alkaline quality of the water as compared to the other sites. Additionally it had hypolimnetic, non-hydropower releases.

9. Temperature and dissolved oxygen data were monitored at each of these locations throughout the summer to determine when reservoir conditions were best suited to conduct each tailwater study. The major emphases of these studies were:

> a. Characterization of the water quality of the reservoir before and after each tailwater study.
>
> b. Characterization of the water quality at stations located downstream from each dam under two flow regimes.
>
> c. Laboratory studies to determine changes in water quality which occurred in reservoir samples following the introduction of oxygen.

10. This report provides information on improved sampling/analysis techniques used in assessing tailwater quality. In addition, it presents stream-gaging methods used to obtain channel geometry and dye study techniques used to measure time of travel. This report also provides a descriptive

interpretation of the data. A more detailed interpretation of the data in this study would require additional data analysis, which is beyond the scope of this report, but will be addressed in a future report.

11. The report is organized as follows: (a) field and laboratory methods used in the study, (b) results from all field study sites, (c) a summary of the water quality chemical transformations, and (d) recommendations for analytical methods and further research in reservoir tailwaters. The results of some of the development work conducted at the Lake Greeson tailwater during the summer and fall of 1987 are included in Appendix A along with other oxygen consumption analyses conducted at the field sites. Appendixes B and C contain tabular and graphical (respectively) representations of the data.

PART II: FIELD AND LABORATORY METHODS

12. All field studies in this work were conducted under steady-flow conditions. Steady flow greatly reduces the complexity of the tailwater studies, thus allowing a clearer examination of the chemodynamics (Dortch and Martin 1989). Unsteady flows make it difficult to decipher hydrodynamic and chemodynamic processes. Hydrodynamic processes are relatively well understood, whereas chemodynamic processes in streams are not (Dortch and Martin 1989). The steady flow condition also imposes a fairly steady-state water quality condition at each station. However, there can be diel fluctuations in water quality at each station resulting from day-night fluctuations in temperature and light (Dortch and Martin 1989).

13. Sampling stations were established at varying distances below the dam for each tailwater (Tables 1 through 4). A sampling station in the reservoir was established at each study site as well. Each reservoir station was located over the old river channel at a distance ranging from 100 to 400 m upstream from the dam. Locations of tailwater and reservoir stations are indicated in Figures 1 through 4.

Time-of-Travel Studies

14. Time of travel (TOT) to each of the downstream stations must be known in order to make meaningful interpretation of the data and to provide the basis for the Lagrangian sampling method (to be discussed later in this section). With travel times, the reaction kinetics of various constituents, such as the loss of reduced manganese, could be evaluated. Travel time was measured by tracking fluorescent dye injections throughout the study reach at each site, except at Canyon Reservoir, where it was estimated (Table 4). The results of the dye studies are given in Tables 1 through 3. Using channel geometry and stream gaging data collected at each site, time of travel at various flows can be estimated.

Stream gaging

15. Channel geometry information (i.e., stream gaging for depth and top width) was obtained at all field sites (except Canyon Reservoir) at stations where water quality data were collected. Stream gaging was performed before the travel time studies and water quality sampling. The method of measurement for each cross section depended on the depth of the water. For instance, if

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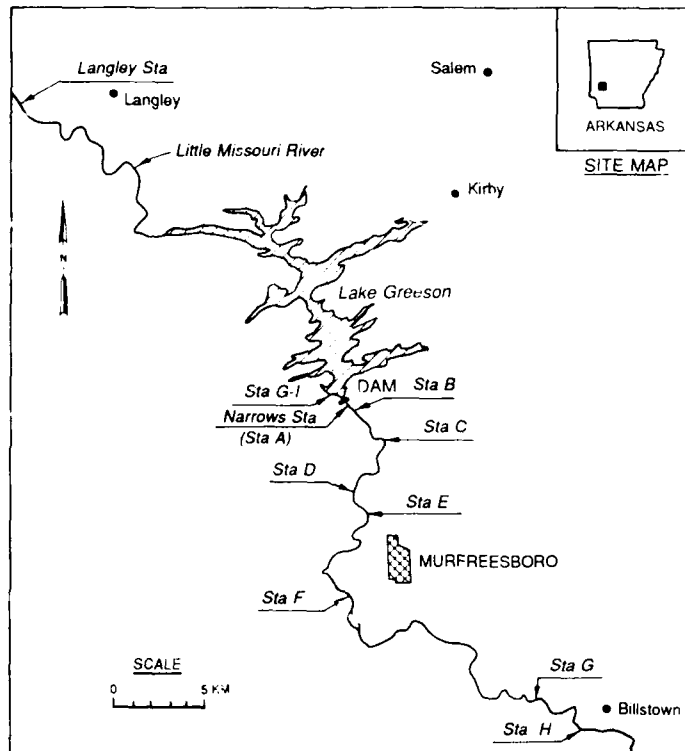
Figure 1. Study site map and station locations for Lake Greeson study
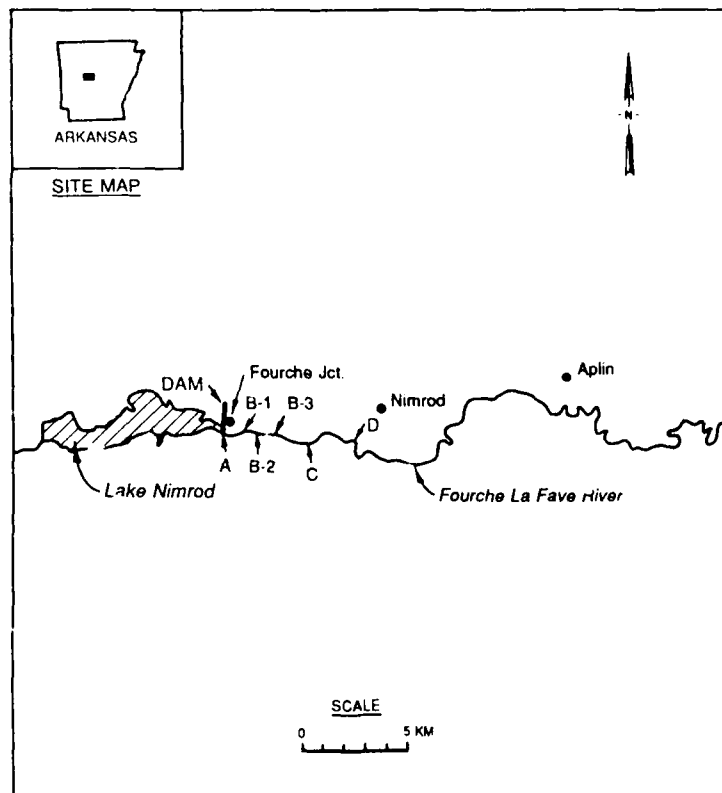
Figure 2. Study site map and station locations for Lake Nimrod study
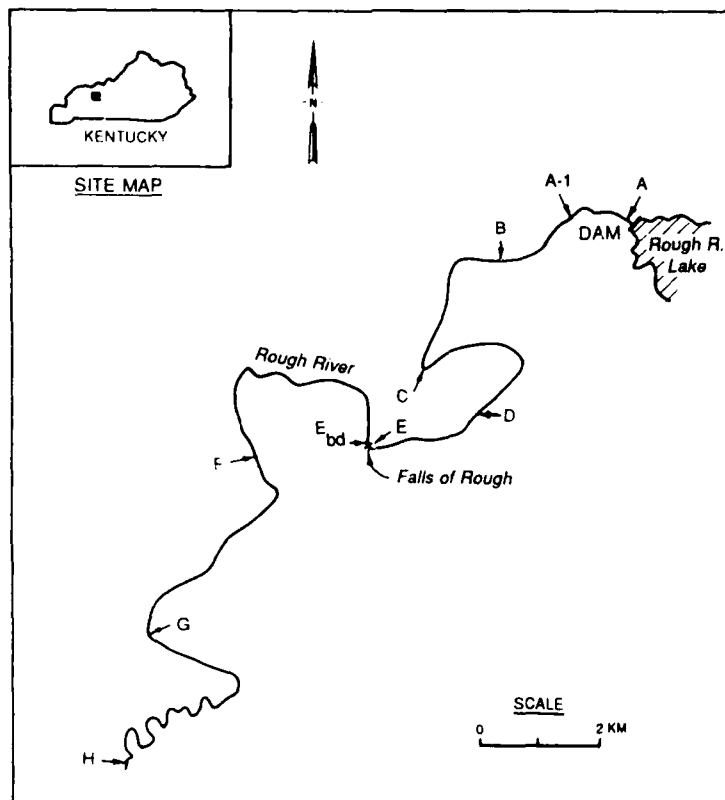
Figure 3. Study site map and station locations for Rough River Lake study
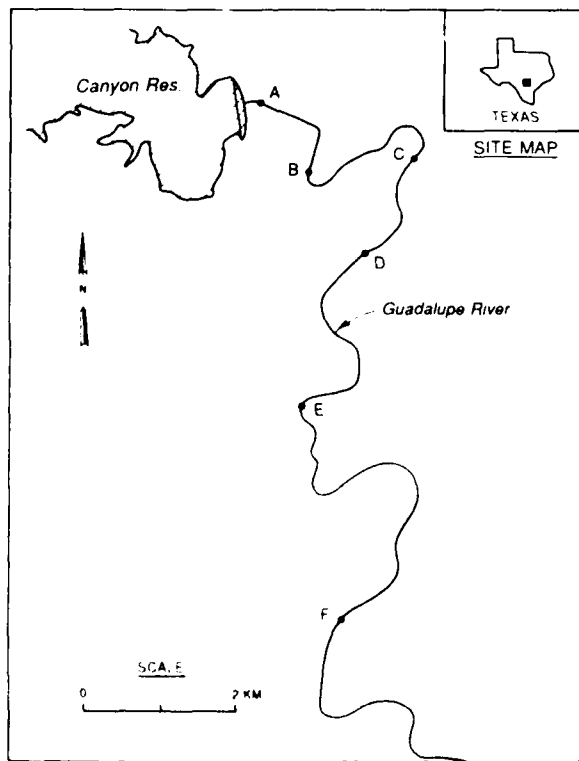
Figure 4. Study site map and station locations for Canyon Lake study

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the water depth was shallow enough to wade, a wading rod was used to measure depth using a marked tag line stretched across the river at right angles to the direction of flow (Herschy 1985). The tag line served as a guide for measuring from left to right bank every 10 ft* and also served the purpose of measuring the top width of the channel. If wading was not possible, a boat was used to measure depth by dropping a sounding reel mounted on a bridge board into the water and taking the measurement. Again, a tag line was stretched across the river as discussed above, and used as a guide for taking depth measurements every 10 ft.

16. From the cross-section information, steady flow travel times were estimated between each sampling station for planning the time-of-travel study. These estimated travel times were needed to insure that monitoring crews were in place at the sampling stations to record the peak dye concentration when it passed through the station. The cross-sectionally averaged velocity at each station was calculated using the relationship

$$R = \frac{A}{P} \tag{1}$$

where: R = hydraulic radius, ft

A = cross-sectional area, sq ft

P = wetted perimeter, ft

and Manning's equation

$$\dot{V} = \frac{1.48}{n} \times \left(R^{2/3} \times S^{1/2} \right) \tag{2}$$

where: V = cross-sectionally averaged velocity, ft/sec

n = Manning's n , dimensionless

S = channel slope, dimensionless

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Once velocity was calculated, an estimated travel time (TOT) to each station was calculated using the relationship:

$$TOT = \frac{L}{V} \qquad (3)$$

where: L = distance between stations, ft

Dye studies

17. Dye injections at each tailwater were conducted with concentrated (20 percent wt/vol) Rhodamine WT dye (Crompton and Knowles Company, Reading, PA), a fluorescent compound commonly used in water tracer studies (Johnson 1984). Actual doses of dye used at each site were estimated using methods described in Johnson (1984) and were to provide a concentration at the most downstream site not to exceed 20 parts per billion (ppb). Dye injections were conducted after 1 to 2 hours of sustained release at prescribed flows to allow time for downstream flushing and establishment of steady flow. Using time-of-travel estimates from hydraulic calculations, downstream stations were routinely sampled for dye starting 1 to 2 hours earlier than the estimated time of travel. Fluorescence was measured in situ with flow-through fluorometers (Turner Designs, Inc., Mountain View, CA) on samples pumped from middepth at a midstream location. Instruments were calibrated using previously standardized dye solutions of known concentration prior to and periodically throughout sampling at each station. Upon arrival at each station, background fluorescence was determined and sampling was conducted at 10-30 min intervals until arrival of detectable concentrations of dye. Detectable concentrations were monitored at 5-min intervals at each site until well after maximum concentrations had been observed. Arrival time of maximum concentration was used for time-of-travel determinations.

18. At Lake Greeson, 1 ℓ of concentrated dye was injected in the lake by bursting a glass container at a depth corresponding to the center line of the penstock (488.1 ft). This method of injection provided adequate mixing of the concentrated dye during release. Three equivalent doses were injected at 2-hr intervals, providing verification of steady-state conditions. Monitoring of dye concentrations during the entire passing of the dye plume was conducted at station E, due to the presence of a potable water intake in the vicinity of station E. As an added precaution, operators of the water intake provided a

12-hr moratorium on withdrawal of river water coincident with estimated time
of travel.

19. The immediate tailwater at Lake Nimrod is a relatively deep pool,
which would inhibit mixing of concentrated dye, necessitating dye injection at
station B1. A 1-ℓ solution of concentrated dye was diluted with approximately
60 ℓ of river water in a large plastic container, mixed, and injected quickly
into a mixing area (rapids) at station B1. Morphometric conditions of the
area immediately downstream of the injection site resulted in travel of the
dye plume along the left stream bank; well-mixed conditions were observed at
station B3.

20. A lack of morphometric data, insufficient initial dye concentra-
tion, and difficulties encountered during sampling for the dye plume resulted
in valid observation of the dye plume only at station B3 on the Nimrod tail-
water. The tailwater reach between stations D and B3 was considerably deeper
and wider than had been anticipated. Consequently, mathematical estimates of
time of travel and the initial dose of dye were incorrect. Sampling was con-
ducted at stations B2 and C, but detectable concentrations were not observed.
The field crew at station B2 was located on the right stream bank, due to
limited accessibility, and only visual observation of the dye plume along the
left bank was possible. Dye concentrations observed at station B3 were near 7
ppb and were discernable from background concentrations near 1 ppb. However,
continuous monitoring at station C resulted in maximum concentrations very
near background levels and determination of time of travel to station C was
not possible.

21. Continued monitoring for dye at downstream stations was determined
to be nonproductive and time-of-travel estimates for water quality sampling
were recalculated using additional morphometric data. A second injection was
not conducted due to limitations of maintaining a sustained release. In
retrospect, a second, larger injection at station B3 during initial passing of
the dye plume would have allowed efforts to continue. This would have
required the field crew to have available a sufficient volume of dye concen-
trate. Additional efforts to determine time of travel from station A to sta-
tion B3 were conducted by visually tracking a 100-ml injection of concentrated
dye. A second time-of-travel study using Rhodamine WT dye was conducted by
Ouachita Baptist University (OBU) personnel on July 11-12, 1989. Travel times
between all stations in Table 2 were obtained except between stations B3 and C
during this study. Incorrect geometry data resulted in the overestimation of

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travel time between these two stations, thus causing the sampling crew to miss the peak dye concentrations. A supplemental study was conducted by OBU personnel on August 8, 1989 which enabled them to verify the travel time between stations B3 and C (Table 2).

22. At Rough River Lake, accessibility and sampling by boat were possible and more detailed morphometric and hydraulic information provided better guidance for the dye study. Five litres of concentrated dye was diluted with approximately 60 ℓ of river water and quickly injected into surface waters at midchannel at station A. Additional mixing was provided by circular movement of two powerboats in the dye plume as it moved downstream. Adequate mixing was observed as the dye plume reached station B. Visual observation of the dye plume was possible as far downstream as station E. Measurable dye concentrations were monitored at stations F and G and time-of-travel estimates were recalculated based on arrival of the dye plume.

23. The Canyon Lake field site was not studied as extensively as the other field sites because of funding and time constraints; thus, a modified study was conducted. A TOT study was not included in the modified study plan. Travel times between stations were estimated using Manning's equation (discussed in the Stream Gaging section) and the US Geological Survey (USGS) rating table for the Sattler gaging station. The estimated travel times are presented in Table 4.

Water Quality Sampling and Analyses

24. A field laboratory was used during the studies at Greeson, Nimrod, and Rough River Lakes. This laboratory consisted of a 10-m trailer which had been fitted with laboratory bench space. The equipment necessary for sample treatment as well as that necessary to conduct some of the more critical analyses were also provided in this laboratory.

25. Two types of water quality sampling were conducted on the tailwaters of Greeson, Nimrod, and Rough River Lakes. First, in an attempt to simulate sampling of a single parcel of water as it moves downstream (Lagrangian sampling), samples were taken at a time which corresponded to time of travel plus 2 hr from the time the first sample was taken in the immediate tailwater (station A). For simplicity, samples taken in this manner are referred to as time-of-travel samples. Secondly, after a specified discharge had been maintained for enough time for a parcel of water to travel to the

most downstream station, snapshot samples were collected at or near the same point in time (usually within an hour). Samples taken in this manner are designated as steady-state or snapshot samples. Both sampling methods have yielded similar results for steady-flow conditions, which means the stream was in a nearly "steady-state" condition.

26. In order to determine the condition of each reservoir during the period when the tailwater was sampled, samples were taken at the station located in the reservoir immediately upstream from the dam (at varying elevations) immediately before the initiation of tailwater sampling. The reservoir was also sampled immediately after the tailwater sampling. In some cases, in situ measurements of temperature, dissolved oxygen, pH, and specific conductance were determined while tailwater sampling was being conducted. These samples are designated as reservoir profile samples.

27. Temperature, dissolved oxygen, specific conductance, and pH were measured in situ using a Hydrolab Surveyor II. The Hydrolab Surveyor II (Hydrolab Corporation, Austin, TX) was calibrated per manufacturer's guidelines (Hydrolab Corporation, 1985) before use each day and again at the end of the day to determine if instrument drift had taken place.

28. A van Dorn type water sampler was used to obtain samples from specified elevations in the reservoirs. Water samples from the tailwaters were obtained as grab samples from midstream and middepth or at a location where the river was well mixed. Samples taken midstream at a point where the stream appeared to be well mixed assume that the grab sample method is valid. It would be necessary to verify sampling protocol through sample replication if heterogeneity is possible at a particular location.

29. Immediately after the sample was taken, subsamples for chemical analysis were prepared (Table 5). Treatment of aliquots A, B, C, and D was accomplished at the sampling site, while treatment of aliquots E, F, and G was accomplished in the field laboratory (less than 1 hr after sampling).

30. Specific parameters analyzed and analytical methods used are summarized in Table 6. Analysis for free carbon dioxide, alkalinity, laboratory pH, total inorganic carbon, chloride, nitrate, nitrite, and sulfate were conducted in the field laboratory located at the study site. Ammonia nitrogen was also determined at the field laboratory at the Rough River Lake site.

31. The field laboratory was not utilized at the Canyon Lake tailwater site. For this study, all sample treatment and preservation was conducted immediately after collection of the sample. Samples were placed on ice and

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shipped by Federal Express to the OBU Laboratory where analyses were con-
ducted. The shipping of the samples resulted in a 24-hr delay in analysis.

32. The occurrence of sulfide in anoxic reservoir water is relatively
common (Gunnison and Brannon 1981). In some instances the odor of hydrogen
sulfide (or a related compound) is present in the upstream section of tail-
waters. This odor was noted at the tailwater regions of Nimrod, Rough River,
and Canyon Lakes. It had been noted at the tailwater of Greeson Lake during
earlier years but not during this study. In order to evaluate sulfide oxida-
tion kinetics in the tailwater, the concentration of sulfide must be deter-
mined. The analytical methods normally used to determine sulfide may not be
directly applicable to determining the sulfide concentration in tailwaters.
First, sample preservation may be impossible since oxygen has already been
introduced into the system at the time of collection. Second, sulfide may be
present as the sulfide ion (S^{-2}), bisulfide ion (HS^-), or as an insoluble sul-
fide such as FeS or FeS_2. The standard iodometric titration is not sensitive
enough to give reliable values in the 0.00 to 0.50 mg/ℓ range. Ion chromato-
graphy using ultraviolet detection is quite sensitive (Waters 1985) and is
capable of detecting 0.001 mg/ℓ of sulfide. The eluant used in the ion
chromatography procedure had a pH of near 6 which means that the actual
species which was being detected was the bisulfide ion. This method would not
detect insoluble sulfides such as iron sulfide. Even with a strong odor of
hydrogen sulfide present in the Nimrod tailwater, sulfide could not be
detected using ion chromatography. For this reason, it seems likely that most
of the sulfide was present as insoluble iron sulfide with any "excess" hydro-
gen sulfide being released to the atmosphere quickly after reaeration.

33. Late in this program the method of Hongzhang (1982) was used to
determine sulfide. Although sulfide was detected in the Canyon Lake tailwater
using this field titration method, it is not clear if it detects only soluble
sulfide or particulate and soluble sulfide. Additional work is being con-
ducted to determine a method which will detect total sulfide in water with a
high iron concentration. Since the most likely product of oxidation of sul-
fide is sulfate, an increase in the concentration of sulfate may be the best
indicator of sulfide which has been oxidized.

34. In order to provide more detailed evaluation of reactions occurring
in the tailwaters, laboratory studies consisting of the analysis of the chemi-
cal composition of samples taken from various depths in Greeson, Nimrod, and
Rough River Lakes were conducted over a period of 10 days. Samples were

obtained from three elevations in each of the reservoirs after anoxic conditions had been established in the hypolimnion. The depth for each of the samples was chosen so that one would be within the mixed epilimnetic layer, one from the mid-hypolimnion and one from a point approximately 1 m above bottom. These samples were transported to the OBU Laboratory (Field laboratory for the Rough River Lake study) where they were aerated by shaking in the presence of air. Immediately after aeration, portions of the sample were placed in 300-ml bottles fitted with ground glass stoppers (bottles commonly used in biochemical oxygen demand (BOD) analysis). The BOD bottles were incubated at 20° C in the dark. Three bottles were used to determine initial concentrations of selected chemical constituents. Three bottles were then removed at selected intervals throughout a 10-day period. The following parameters were determined in each of the BOD bottles immediately after removal from the incubator: dissolved oxygen, total organic carbon, total Kjeldahl nitrogen, nitrate nitrogen, ammonia nitrogen, nitrite nitrogen, sulfate, sulfide, total and dissolved iron, total and dissolved manganese.

35. The OBU Laboratory participates in both an internal and external quality assurance program. Internal quality assurance is provided through a program of replicating selected samples, spiking selected samples, and spiking a blank sample. External quality assurance consists of periodic analysis of standards furnished by the US Environmental Protection Agency (Cincinnati Laboratory) and participation in a quality assurance program sponsored and monitored by the USGS. The USGS program consists of a blind audit conducted two times per year.

PART III: RESULTS AND DISCUSSION

36. Results from each study are discussed separately in the sections that follow. The tabular data obtained in each of the tailwater studies are presented in Appendix B, and selected data from Appendix B are presented in graphical form in Appendix C.

Lake Greeson Study

Narrows Dam site description

37. Narrows Dam, a multiple-purpose project for flood control and power generation constructed by the Corps of Engineers in 1950, is located in southwestern Arkansas at river mile 105.5 on the Little Missouri River, a tributary of the Ouachita River. The dam site is approximately 11.4 miles upstream of Highway 27 near Murfreesboro in Pike County, Arkansas. The drainage area contributing to the reservoir is 237 square miles or about 11.4 percent of the Little Missouri River basin. In general, the area above the dam is mountainous and largely covered with timber with scattered level-to-rolling areas partially devoted to agriculture. Below Murfreesboro, the main stream enters the coastal plain where it flows in a flat-bottomed valley from 1 to 4 miles wide. The channel width ranges from 150 to 400 ft between banks. The river slope varies from 4 ft per mile near Murfreesboro to less than 2 ft per mile near the mouth.

38. Characteristics of Lake Greeson, which was formed by this dam, are summarized below.

Drainage area	237 square miles
Maximum power pool el	548 ft (NGVD)*
Maximum power pool area	7,200 acres
Storage of conservation pool plus power pool	2.8×10^5 acre-ft
Center-line el of penstock	488.1 ft (NGVD)
Bottom el at dam	397.5 ft (NGVD)

39. The dam is of concrete gravity construction and has two non-overflow abutment sections, a flood-control section containing two conduits, 8.5 ft in diameter, each regulated by a 7-ft-diam Howell-Bunger Valve,

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

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a 150-ft uncontrolled overflow spillway section and stilling basin, and a power intake section containing three penstocks, 10 ft in diameter.

40. The power plant consists of three vertical type, 8,500-kw, generating units and control, switching, transforming, and operating equipment incidental thereto. Remote control facilities were scheduled for completion during FY 1971. The remote control facilities are located at the Blakely Mountain powerhouse, which will operate the Narrows, DeGray, and Blakely Mountain plants.

Lake Greeson results

41. Anoxic conditions had been observed at the elevation of the intake structure at Lake Greeson during previous years (Nix 1983). The data obtained during the summer of 1987 (Figures C1 and C2) clearly indicated that the rates of oxygen depletion in the hypolimnion and the metalimnion were not as great as those observed during earlier years. Even though conditions for the introduction of elevated concentrations of reduced chemical species into the Greeson tailwater were not favorable, it was necessary to continue the study.

42. Comprehensive oxygen consumption studies were conducted at the Greeson site during the summer of 1987 to determine the appropriate emphasis in all subsequent field studies. The results of these studies are summarized in the first part of Appendix A. Some of these methods were found to be irrelevant and were not pursued further.

43. Arrangements were made with the Corps of Engineers to provide a sustained 14.2-m^3/sec (500-cfs) release for 6 hrs beginning at 1200 hr on July 28, 1987. Reservoir profiles for in situ parameters at 1-m intervals and water chemistry at 2-m intervals were obtained immediately prior to the initiation of releases and just before completion of the 6-hr generation period (Figures C1 and C2). Water chemistry data for Lake Greeson on July 28, 1987 are summarized in Figures C3 through C6. The purpose of the study conducted during this 6-hr release period was to develop logistics for sample handling and preservation and to sample the tailwater at station B to determine if the quality of water released changed during prolonged generation. The results of the analysis of samples taken at station B immediately prior to the initiation of generation and during the 6-hr generation period are given in Figures C7 through C11. Prior to generation, the flow of the Greeson tailwater in the vicinity of the dam was essentially leak water. The fact that this leak water is colder than water released through the generating facility indicates that

it is originating from points deeper in the reservoir than the penstock. The discharge of leak water was estimated to be around 0.14 m^3/sec (5 cfs).

44. As shown in Figures C7 through C11, following some initial fluctuations as the tailwater began to fill with water which had passed through the generating facility, the observed chemical parameters remained essentially constant throughout the 6-hr generation period. The data indicate that the first two samples taken in this series reflect a transition state from leak water to water being released through the generating facility. Mean and standard deviation values for the 18 samples taken after this transition are shown in Table 7.

45. The standard deviations obtained from these data suggest that only minor changes occurred after the initial washout period. The dissolved oxygen concentration was observed to decline during the later portion of the 6-hr generation period. It was determined that the observed drop was due to instrument drift. For this reason, the dissolved oxygen (DO) measurements made at station B on July 28, 1987 were not valid.

46. Since anoxic conditions had not developed at the elevation of the penstock, the concentrations of reduced chemical species were not elevated above that of the oxygenated epilimnetic water. The concentration of nitrate nitrogen in the epilimnion of Lake Greeson was observed to be very low while concentrations in the metalimnion and hypolimnion were in the range of 0.20 to 0.30 mg/ℓ. The profile of nitrate nitrogen in the reservoir (Figure C6) showed a relatively sharp gradient of concentration near the elevation of the penstock. For this reason, nitrate nitrogen data should be of some use in verifying the ability of such models as SELECT (Davis et al. 1987) to predict the concentration of various components in the tailwater. Temperature can also be used to verify such models but other chemical parameters did not change enough near the elevation of the penstock to make such an evaluation. From the consistency of the nitrate nitrogen data at station B during the 6-hr release period, it is reasonable to conclude that the zone of withdrawal did not change during the 6-hr generation period.

47. A complete tailwater study was conducted in the Greeson tailwater during a 48-hr generation period which took place on September 12-14, 1987. Generation began at 0800 hr on September 12, 1987 with a discharge rate of 14.2 m^3/sec (500 cfs). As shown in Figures C12, C13, and C14, slightly elevated concentrations of free carbon dioxide, iron, and manganese and slightly depressed concentrations of dissolved oxygen (Figure C18) were observed in the

metalimnetic region on September 12, 1987. The results of the analysis of samples taken at station A throughout the 48-hr release period are shown in Figures C15 and C16. After an initial period of flushing, the concentration of most of the parameters stabilized. Omitting the first three measurements, means and standard deviations for each of the parameters were calculated, and the results of these calculations are given in Table 8.

48. Although the exact standard deviation for a set of replicated samples was not determined, the standard deviation for most of the parameters was near that routinely observed for a set of replicated samples in this laboratory. The parameters which were most likely to show changes at station A if the extent of the withdrawal zone changed during the period of generation would be those which showed gradients in the water column near the elevation of the intake structure. The parameters which showed gradients near the depth of the intake structure were temperature, dissolved oxygen, and nitrate nitrogen. The correlation coefficients (r) and slopes determined from a regression of data from station A with time are given in Table 9. The lack of a significant relationship suggests that the variations observed throughout the 48-hr release period were essentially random.

49. In situ measurements were made at 1-m intervals at station 1 both before and after the 48-hr generation period. Samples were also taken and subjected to analysis for several water quality parameters. As discussed above, the parameters which showed gradients at a depth corresponding to the depth of the intake structure (center line at approximately 11 m) were temperature, dissolved oxygen, and nitrate nitrogen. The profiles for each of these parameters before and after the 48-hr generation period are shown in Figures C17, C18, and C19. Although the values obtained for dissolved oxygen were slightly less following the 48-hr generation period (Figure C18), a check of post-measurement calibration for that day indicated that there had been approximately 0.5 mg/ℓ drift of the Hydrolab water analysis instrument. Other than this overall 0.5-mg/ℓ reduction in concentration, the pattern of dissolved oxygen distribution observed before and after the generation was very similar to that observed prior to the initiation of generation. As shown in Figures C17 and C19, the patterns for temperature and nitrate nitrogen were also very similar before and after the 48-hr generation period. These observations suggest that changes were relatively small in the chemical and physical structure of the water column during the generation cycle.

50. The second sampling of the Greeson tailwater was conducted near the end of the 48-hr generation period. Samples were taken as a snapshot at all stations during a 1-hr period. Since the time of travel to the most downstream station was exceeded (Figure C20), it was assumed that the tailwater was in a steady-state condition.

51. The values obtained at each of the tailwater stations for steady-state and time of travel sampling during the September 12-14, 1987 study are compared in Figures C21 through C39. In general, the patterns for data obtained using the two sampling strategies were similar. It should be noted that anaerobic conditions were still not present in Lake Greeson at the depth of the intake structure. For this reason, the concentration of reduced chemical species usually present in anaerobic lake water was not high enough in the tailwater to make a good comparison between the two sampling methods. The values for temperature, dissolved oxygen concentration, pH, and total manganese concentration did vary enough to make a limited comparison of the two sampling regimes. The results of a regression of these parameters with distance below the dam for the two sampling regimes are given in Table 10.

52. The fact that water temperature was slightly higher at stations A through D for the time-of-travel sampling as compared to the SS sampling can easily be explained since the TOT samplings were made during daytime and SS sampling took place around 0400 hr. A similar situation exists for differences in the DO concentrations.

53. The temperature of water at station A during the 48-hr study in September was near 14° C (Figure C21). The DO concentration increased from near 4 mg/ℓ at station A to near 8 mg/ℓ at station E. Although the relationship between DO and distance is not linear, the initial increase was at a rate of approximately 0.4 mg/ℓ/km. The concentration of DO was not observed to increase downstream from station E (Figure C22). It is interesting to note that the DO concentration did not reach saturation levels even in the downstream section of the tailwater.

54. The trend of pH was to increase slightly in a downstream direction (Figure C23). This change is most likely due to the loss of carbon dioxide from the system. When sampling deep hypolimnetic water, it is not uncommon for the pH of a sample to increase over one pH unit during the first few minutes following collection, indicating a loss of free carbon dioxide.

55. Although the specific conductance of the Greeson tailwater is relatively low (Figure C24), no change in specific conductance was observed

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throughout the study region. In a low dissolved solids system such as the Greeson tailwater, the main factor which could alter the specific conductance would be the loss of dissolved iron and manganese. .nce the concentration of these components was not very high, little change would be expected.

56. Free carbon dioxide dropped quickly during the first 10 km of the tailwater (Figure C25). As mentioned above, this loss of carbon dioxide resulted in an increase in the pH of the system.

57. Although there appears to be a slight increase in alkalinity in a downstream direction (Figure C26), the magnitude of the increase is small compared to the measured value for alkalinity. It should also be recognized that a standard alkalinity titration was used for these samples. At alkalinities under 10, this method should be replaced with Gran Plot titration (Stumm and Morgan 1970). For these reasons, no significance should be given to changes which were observed for alkalinity.

58. Total inorganic carbon (TIC) probably reflects mostly carbon in the form of bicarbonate (Figure C27). Although the determination of TIC was made at the field laboratory, even the small delay before analysis probably was enough to cause some loss of free carbon dioxide. Actual TIC would probably be best estimated by adding carbon in the form of free carbon dioxide and measured T_i .

59. Both total organic carbon and dissolved organic carbon were relatively constant throughout the Greeson tailwater (Figures C28 and 29, respectively). The method used to determine organic carbon was the wet persulfate method. This method consists of acidification of the sample, purging with nitrogen gas to remove inorganic carbon, adding an oxidizing agent, ampulation, heating (autoclave), then measuring the carbon dioxide formed. It is likely that any volatile organic carbon present would be removed during the purging step. At this point, we cannot discount the possibility that volatile organic compounds may be present in the tailwater that could be important in the oxygen dynamics of the system.

60. A small increase in sulfate occurred in a downstream direction (Figure C31). The possibility that this increase in sulfate concentration was due to the contribution of sulfate from tributaries or groundwater cannot be completely eliminated. However, since the discharge of the Greeson tailwater was near 14.2 m³/sec (500 cfs) and tributaries were at a very low stage, it seems unlikely that this could account for the observed increase in sulfate. It is more likely that the increase in sulfate is due to the oxidation of

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sulfides originating in the depressed oxygen zone of the reservoir. Although no odor of sulfide was present during the study, sulfide could be present as iron sulfide. Even though there may be other explanations for the increase in sulfate concentration, the observed increase sets the upper limit of sulfide oxidation which could have taken place in the tailwater.

61. Both total manganese and dissolved manganese were observed to decrease in a downstream direction in the Greeson tailwater (Figures C32 and C33, respectively). The slope of a regression of total manganese and dissolved manganese with distance gives slopes of 0.002 mg/ℓ/km. Compared to previous years, the manganese concentration in the tailwater was low. Even with the low concentration of manganese, the decrease in a downstream direction was observed. The concentration of manganese in the tailwater decreased from near 0.10 mg/ℓ to near 0.04 mg/ℓ 18 km downstream. A concentration of 0.04 mg/ℓ is near background values for oxygenated water in this section of Arkansas (Nix 1986). It is important to note that the concentrations of total and dissolved manganese were essentially the same. This suggests that manganese is being removed from the water column onto stream substrate rather than precipitating in the water column and being transported as particulate manganese. Work by Nix (1986) has shown that the surface of manganese-oxide-coated gravels in the Greeson tailwater are extremely efficient in adsorbing dissolved manganese. Stumm and Morgan (1970) point out that the most logical mechanism for the oxidation of manganese is for the manganese II ion to become adsorbed onto a manganese oxide surface followed by a slower oxidation on the manganese oxide surface. Gordon (1989) reports that manganese in the Normandy tailwater was probably being removed by a "slime" on the surface of gravels.

62. Attempts to measure the oxidation rate of manganese in a laboratory situation have shown that the reaction is very slow at a pH of 6 to 7 (Stumm and Morgan 1970). The work by Nix (1986) has shown that reduced manganese (manganese II) is quickly removed by oxide-coated surfaces. For this reason, removal of manganese from the tailwater cannot be used as an indicator of the oxidation of reduced forms of manganese. It is more likely that removal of manganese from the tailwater is due to adsorption onto oxide-coated gravels or other stream substrate. Oxidation then occurs after adsorption. Stumm and Morgan (1970) indicate that the actual oxidation reaction is quite slow. If this is the case, the role of manganese in the dissolved oxygen dynamics of a tailwater may be minimal. Experiments are currently under way in this

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laboratory to confirm the rate of manganese oxidation following adsorption onto oxide-coated gravels.

63. The concentration of iron in the tailwater was not high enough to investigate trends. It is interesting to note that the concentration of total iron (Figure C34) is higher than dissolved iron (Figure C35) suggesting that particulate iron was present in the tailwater system. This observation, along with other data (discussed later), indicates that the oxidation of reduced iron (iron II) occurs in the water and not after adsorption (as is the case with manganese). Numerous investigators have also observed that the rate of oxidation of reduced iron is rather fast (Stumm and Morgan 1970). This suggests that the oxidation of iron may have the potential to affect the oxygen dynamics of the upstream section of the tailwater system.

64. The concentration of ammonia nitrogen in the Greeson tailwater was very low (Figure C37). The concentration of nitrate nitrogen in the Greeson tailwater was considerably higher than ammonia nitrogen (Figure C36). Although nitrate nitrogen is one of the products of ammonia oxidation (Reddy and Patrik 1984), the amount of nitrate which could be produced by this reaction was small compared to the concentration of nitrate already present. There was, however, a decrease in the nitrate concentration in a downstream direction. This trend was probably due to biological uptake of nitrate or denitrification.

65. A modified sampling of the downstream tailwater stations was conducted on October 14, 1987. The release of approximately 14.2 m^3/sec (500 cfs) began at 0800 hr and extended to 1400 hr (6 hr). Samples were taken from station 1 in Lake Greeson immediately prior to the initiation of generation. As shown in Figures C40 and C41, the concentrations of iron, manganese, and ammonia in the deep hypolimnion were slightly higher than those observed in September (see Figures C13 and C14). The manganese concentration at the depth of the intake structure was also slightly higher than that observed during the September study.

66. In general, the results of the tailwater study conducted on October 14, 1987 (Figures C42 through C46) confirm the observations made in the July and September studies. The manganese concentration was slightly higher but the development of anoxic conditions had not proceeded to the point where significant concentrations of ammonia nitrogen or iron were present.

67. Samples for the 10-day BOD incubation were obtained from elevations in Lake Greeson corresponding to depths of 3, 9, and 41 m on August 25, 1987

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and from 4, 14, and 39 m on November 4, 1987. The samples were aerated, then
sealed in BOD bottles. Three bottles for each depth were removed from the
incubator at specified times throughout the 10-day period. The results of the
triplicate analysis (a, b, and c) along with the mean (x) for both dates are
shown in Table B9 and Table B10, respectively. The mean values for the trip-
licate analysis are plotted against time in Figures C47 through C52 for the
August 25 study and in Figures C53 through C59 for the November 4 study.
Water quality conditions present in the reservoir at the time these samples
were taken are shown in the tabular section of this report (Appendix B).

68. Dissolved oxygen concentration declined throughout the 10-day incu-
bation period. In the August study, reservoir oxygen depletion had not pro-
gressed to the point where high concentrations of reduced species were present
in even the deepest sample. By November, the concentration of reduced species
in the deepest sample had increased significantly. A comparison of the dis-
solved oxygen concentrations in the August study to those in the November
study shows that the dissolved oxygen decrease throughout the 10-day period
was similar in epilimnetic and hypolimnetic samples in the earlier study, but
different in the November study. This difference is probably due to the oxy-
gen consumption of some of the reduced chemical species. There appears to be
a slight decrease in organic carbon throughout the incubation period. The
rate of decrease is very similar for epilimnetic and hypolimnetic samples.

69. The concentration of dissolved iron throughout the incubation
period was erratic, but total iron concentration was practically constant
(Figure C55). No firm explanation can be offered to account for this observa-
tion other than the fact that ferrous and ferric iron interactions are compli-
cated when iron sulfide oxidation is involved. The manganese concentration
decreased only slightly during the incubation period, confirming the observa-
tion of other investigators (Stumm and Morgan 1970) that this reaction is slow
when catalyzing oxides of manganese are not present. The ammonia nitrogen
increased in the earlier study but decreased in the later study. The oxida-
tion of ammonia to nitrate could easily account for the decrease in the latter
study. The increase in ammonia nitrogen in the earlier study may reflect
mineralization of organic nitrogen. The absence of substrate with nitrifying
bacteria may explain why ammonia is not oxidized in the presence of 6 mg/ℓ of
dissolved oxygen.

70. Although some trends were observed throughout the 10-day incubation
period, it is important to remember that the environment of the BOD bottle is

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very different from that present in the tailwater. Some caution should be used when reaction rates are implied from BOD bottle incubation data.

Lake Nimrod Study

Nimrod Dam site description

71. Nimrod Dam was authorized 26 June 1938 by the Flood Control Act for flood control and other purposes. Operation of the project was initiated in May 1942. Nimrod Dam provides for future hydropower development, but turbine units have not been installed.

72. Nimrod Dam is located on the Fourche La Fave River, 62.6 miles upstream from its confluence with the Arkansas River in west central Arkansas. The drainage area contributing to the reservoir is 680 square miles or about 61 percent of the Fourche La Fave River basin. The region is rugged and wooded and is characterized by a series of roughly parallel mountains with flat ridges separated by deep, narrow valleys.

73. Characteristics of Lake Nimrod, which was formed by this dam, are summarized below.

Drainage area	680 square miles
Maximum flood control pool elevation	373 ft (NGVD)
Maximum flood control pool area	18,300 acres
Storage of flood control pool	3.36×10^5 acre-ft
Center-line elevation of penstock	322.5 ft (NGVD)
Bottom elevation at dam	297 ft (NGVD)

74. The dam is a concrete gravity structure about 80 ft high situated above the valley floor. Seven gate-controlled conduits through the base of the dam are provided which have a capacity of 17,300 cfs with the pool at spillway crest. Two Howell-Bunger valves are installed to permit close regulation of low flow releases.

75. The spillway is uncontrolled and has a net length of 154 ft. The project is designed for future installation of seven 14- by 22-ft tainter gates and two turbine units.

Lake Nimrod results

76. Temperature and dissolved oxygen profiles of Lake Nimrod were furnished by the Lake Nimrod Resource Manager and were supplemented by OBU

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personnel. As shown in Figures C60 and C61, thermal stratification began in mid-May, 1988. The depletion of dissolved oxygen in the hypolimnion also began in mid-May and by July 18, anoxic conditions were present throughout the hypolimnion. The study of the Nimrod tailwater began on July 18, 1988. The discharge rate at Nimrod Dam was approximately 0.57 m^3/sec (20 cfs, low flow) with discharges being made through two Howell-Bunger aeration systems. Since releases had been constant for several days, it was assumed that the tailwater was at a steady-state condition through station D (see Figure 2). Steady-state sampling of the Nimrod tailwater was conducted on July 18, 1988. Samples were taken at stations A through D within a 1-1/2-hr period.

77. At 0800 hr on the morning of July 20, 1988, the discharge from Nimrod Dam was increased to 5.66 m^3/sec (200 cfs). The tailwater was sampled at time of travel plus 4 hr. The 4-hr period was added to the estimated time of travel to minimize any error that might have been made in time of travel estimations. Time-of-travel sampling continued through station D. On the morning of July 22, 1988, steady-state sampling of the tailwater stations was conducted.

78. As discussed above, the temperature and dissolved oxygen data obtained on Lake Greeson before generation and after generation (48-hr study) did not indicate any significant changes in the water column. However, an inspection of temperature and dissolved oxygen profiles observed in Lake Nimrod (Figures C60 and C61) clearly indicates that substantial changes did occur during the course of the study. The dissolved oxygen profile observed at 0715 hr on July 18 showed a mixed layer less than 2 m in depth and anoxic conditions beginning at a depth of 5 m. During the early morning hours of July 20 passage of a cold front occurred and substantial winds were observed to blow from the northwest. This wind persisted throughout the daylight hours of July 20 and subsided around 2000 hr on that same day. The direction of the wind was essentially down lake, blowing directly into the upstream face of the dam.

79. The dissolved oxygen profile obtained at 1145 hr on July 20 showed a thickening of the mixed layer and a thinning of the anoxic layer (see Figure C61). The profile obtained at 1700 hr on July 20 indicated that the mixed layer had thickened even more, now extending to a depth of 7 m. Profiles obtained on July 21 and July 22 show that the process which was occurring in the reservoir reversed and by 1100 hr on July 22, the dissolved oxygen profile was very similar to that observed at 0715 hr on July 18. These observations

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strongly suggest that tilting of the top of the thermocline had occurred in response to persistent northwesterly winds. Relaxation of this condition apparently occurred after subsidence of the winds.

80. Tilting of the thermocline caused by wind events could produce significant turbulent mixing at the boundary between the mixed layer and the anoxic hypolimnion (Fischer et al. 1979). During periods of time when the iron, manganese, ammonia nitrogen, and possibly hydrogen sulfide are present in the hypolimnion, this turbulent mixing could introduce significant quantities of these reduced chemical species into the epilimnion of Lake Nimrod. The fact that the color of the surface water in Lake Nimrod was brown-orange during the period of this study is consistent with the oxidation of reduced iron to the form of iron III hydrous oxides.

81. The tilting of the thermocline and associated mixing altered the nature of water being incorporated into the withdrawal zone and ultimately the water being discharged from Nimrod Dam. Unfortunately, these changes complicate the interpretation of the water quality data obtained in the Nimrod tailwater.

82. Estimated time of travel as a function of distance from the dam is shown in Figure C62. The results of the analysis of samples taken during the study of the Nimrod tailwater are shown in Figures C63 through C76. On these graphs, data taken during low-flow, steady-state conditions are indicated by "A." High-flow, time-of-travel samples are indicated by "B," and high-flow, steady-state conditions are indicated with a "C."

83. The temperature and dissolved oxygen data obtained for these studies are shown in Figures C63 and C64, respectively. The dissolved oxygen concentration decreased at a rate of 0.3 mg/ℓ/km throughout the first 5 km of the tailwater. The dissolved oxygen concentration immediately below the dam (station A) was slightly higher during both high-flow studies. These differences are due to changes in the structure of the water column in the lake as discussed above. The effect of changes in structure of the water column is even more pronounced for other parameters.

84. The pH data for the Nimrod tailwater (Figure C65) is rather confusing. At low flow there was a decrease in pH, and at high-flow, time-of-travel sampling there was an increase, but at high-flow steady-state sampling, there was little change. Changes in pH were probably caused by such factors as loss of free carbon dioxide, oxidation of sulfide, and biological activity. Assuming that the first two of these variables are relatively constant, it is

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likely that varying biological activity (caused by the fact that some samples were taken during daytime and others during nighttime) probably accounts for these observations.

85. The specific conductance of the Nimrod tailwater is relatively low, indicating a low dissolved solids system. The data expressed in Figure C66 show a clear decline throughout the section of the tailwater which was studied. The specific conductance observations at station 1 in Lake Nimrod on July 18 show values near 55 μsec in the epilimnetic layer, increasing to near 80 μsec near bottom. If it is assumed that this increase in specific conductance is due to increases in the concentration of iron and manganese, then the observed decrease in specific conductance at the downstream tailwater stations is consistent with the removal of iron and manganese from the system. The dynamics of these two components are discussed below.

86. As shown in Figure C67, alkalinity also decreases throughout the section of the tailwater which was studied. This decrease of alkalinity suggests the addition of an acidic component into the tailwater system. Other data (see below) suggest that this acidic component originates from the oxidation of some sulfide species, probably FeS_2 or FeS.

87. The total organic carbon in the Lake Nimrod tailwater showed (see Figure C68) an erratic pattern in the first 3 km of the tailwater. The possibility of sample contamination cannot be completely eliminated. As discussed in the Greeson tailwater section, there is the possibility that volatile organics could be present in the tailwater. For example, if the sample at station A at low-flow steady-state conditions had a higher concentration of volatile organics, the purging time used in the analysis may not have removed all of these compounds. This could account for the anomalously high concentration observed in this sample (11 mg/ℓ).

88. The turbidity of the Nimrod tailwater is shown in Figure C69. There is a marked decline of turbidity throughout the section of the tailwater which was studied. The clearing of the tailwater was more pronounced during low-flow conditions. A comparison of the total iron data shown in Figure C73 with turbidity data in Figure C69 shows an excellent relationship between turbidity and total iron (r = 0.99). The turbidity of the Nimrod tailwater is due almost totally to particulate iron which forms in the first 200 m of the tailwater.

89. The sulfate concentrations in the Nimrod tailwater increase in a downstream direction (Figure C70). Although the possibility of the

contribution of sulfate from surface or groundwater cannot be completely elim-
inated, it seems much more likely that this increase is caused by the oxida-
tion of sulfide species in the tailwater. This theory is supported by the
observation that alkalinity decreases throughout the tailwater. As shown by
Stumm and Morgan (1970), the oxidation of iron(II) sulfide (pyrite) is accom-
panied by the release of a hydrogen ion. The addition of a hydrogen ion to
the system would result in decreased alkalinity. Although the magnitude of
the impact would be much less, the reactions involved in such an "acidifica-
tion" would be similar to those observed in areas where pyritic overburdens
from mining are oxidized and the leaching results in stream acidification
(Stumm and Morgan 1970). Since there is considerable difficulty in measuring
total sulfide in tailwater systems, it is suggested that the increase in sul-
fate be used to indicate the amount of sulfide which has been oxidized in the
tailwater.

90. Total manganese and dissolved manganese in the Nimrod tailwater are
shown in Figures C71 and C72, respectively. It should be noted that the con-
centration of manganese at station A is considerably different for each of the
three sets of samples which were obtained. It is clear that the lower concen-
tration observed at high flow reflects changes in the water column (discussed
above) as well as changes in the withdrawal zone in the lake.

91. The dissolved manganese concentration was, in general, about 10 to
15 percent lower than the total manganese concentration at each station. This
suggests that a removal mechanism other than oxidation followed by precipita-
tion in the water column is occurring in the Nimrod tailwater. At low-flow
conditions, the decrease in concentration of manganese throughout the region
of the tailwater studied was pronounced. At the higher flow, the concentra-
tion of manganese appears to remain fairly constant throughout the first 3 km
of the tailwater after which a decline was observed. Beyond the 3-km point in
the tailwater, the decrease in concentration at the different flow regimes was
similar (-0.16 mg/ℓ/km for time of travel and -0.19 mg/ℓ/km for steady state).
The fact that most of the manganese removed from the water does not appear as
particulate manganese in the water column lends support to the idea that
reduced manganese is first being adsorbed onto stream substrate (possibly
gravels) and then undergoing oxidation (Stumm and Morgan 1970). As mentioned
in the discussion of the Lake Greeson tailwater, the removal of manganese from
the water column is probably not a good indicator of manganese which has been
oxidized. The observation that the concentration of manganese is relatively

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constant throughout the first 3 km of the tailwater under high-flow conditions may reflect a change in residence time or hydraulic conditions which would result in lack of exposure to suitable substrate.

92. The distribution of both total and dissolved iron (Figures C73 and C74) in the Nimrod tailwater is different from that of manganese. Although a relatively high concentration of dissolved (assumed reduced) iron was present at the elevation of the intake structure in Lake Nimrod, the tailwater data clearly indicate that oxidation was occurring very quickly and that the product of the oxidation (hydrous oxides of iron III) was present in the water. By the time the release water reached station A (100 m below the face of the dam) essentially all of the dissolved iron was converted to the particulate form of iron. This is supported by the visual observation that the water immediately below the Howell-Bunger valves (first 50 to 60 m) was relatively clear but 25 m beyond that point the tailwater was brown-orange. The oxidation zone for iron in the tailwater is within 50 m.

93. A floc of hydrous oxides of iron III was visible throughout the upstream section of the tailwater. As noted above, there is an excellent correlation between particulate iron and turbidity in the Nimrod tailwater. It appears that although iron oxidation occurs very quickly, the product of this oxidation remains suspended and gradually settles throughout the section of the tailwater which was studied. It is important to understand that the mechanism for removal of iron from the tailwater is different from the mechanism for the removal of manganese.

94. Although the concentration of iron in the tailwater indicates that most of the oxygen demand caused by the iron probably occurred in the first 100 m of the tailwater, the possibility exists that such species as iron sulfide (possibly pyrite, FeS_2) could coprecipitate with the hydrous oxides of iron III and continue to exert an oxygen demand as it is carried downstream. In an effort to determine if the particulate material present in the tailwater was exerting an oxygen demand, a portion of the water from station A was filtered onto a glass fiber filter. The filter was then exposed to potassium permanganate in acidic conditions. Although time did not permit good quantification, it was clear that permanganate was being consumed rather quickly by the particulate fraction. As discussed above (Greeson tailwater), the observation that the sulfate concentration increased in a downstream direction along with the observations that the particulate fraction consumed

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permanganate, gives some support for the idea that particulate iron sulfide may be a factor in the dissolved oxygen dynamics of the tailwater.

95. Attempts to measure sulfide using ion chromatography indicated that the sulfide ion concentration was less than 0.005 mg/ℓ. This observation seemed inconsistent with the fact that a hydrogen-sulfide-like odor was present in the first 300 m of the tailwater. Even samples taken from the deep hypolimnion of Lake Nimrod did not show detectable sulfide, although the odor of sulfide was strong. In order to verify that the ion chromatographic method was working, small aliquots of a solution of sodium sulfide were added to a sample taken near the bottom of the hypolimnion of Lake Nimrod. After each addition, the resulting sample was injected into the ion chromatograph in an attempt to determine the sulfide concentration. After the addition of sulfide (which should have resulted in a concentration of over 1 mg/ℓ) no sulfide was finally detected. After several such additions the sulfide was detected. In other words, the sample was consuming sulfide. The most probable reaction which could account for this sulfide consumption was that iron sulfide was precipitating. If this observation is correct, it further supports the idea that iron sulfide may be present in significant quantities in the Nimrod tail-water. The ion chromatographic method simply does not detect any sulfide which would be present as particulate iron sulfide. Additional work is needed to quantify the amount of sulfide present and to determine if it is an important factor in the dissolved oxygen dynamics of the Nimrod tailwater.

96. The concentration of nitrate nitrogen and ammonia nitrogen in the Nimrod tailwater is shown in Figures C75 and C76, respectively. The inverse relationship between the reduced form of nitrogen (ammonia) and its oxidized form (nitrate) was obvious. Although a concentration of near 0.6 mg/ℓ of ammonia nitrogen was present in the upstream section of the tailwater, it declined to less than 0.2 mg/ℓ throughout the section of the tailwater which was studied. Although nitrate nitrogen increases as the ammonia nitrogen decreases, nitrogen was not conserved. Even after 0.7 mg/ℓ of ammonia nitrogen (low-flow conditions) dropped to less than 0.1 mg/ℓ, a nitrate nitrogen increase of only 0.2 mg/ℓ was observed. This nitrogen deficit may be due to denitrification in stream sediment, resulting in the loss of nitrogen gas or an oxide of nitrogen (Reddy and Patrik 1984). There is also the possibility that a significant portion of the nitrogen may be taken up by algae and other plant material present in the stream. Although the concentration of ammonia nitrogen in the Lake Greeson tailwater was low, the nitrate

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concentration decreased in a downstream direction. This supports the idea that some process, either biological uptake or denitrification, was also occurring in the Nimrod tailwater.

97. The 10-day BOD study of Lake Nimrod water was initiated on July 6, 1988. Samples were taken at depths of 2, 6, and 10 m at the station located immediately upstream from the dam. The samples were transported to the laboratory where they were treated in the same manner as described under the Greeson 10-day BOD study. Triplicate BOD bottles containing samples from each depth were removed from the incubator at 2, 5, 7, and 10 days after the samples had been aerated and sealed. The means of the triplicate analysis are summarized in Figures C77 through C87.

98. The trends observed for the Lake Nimrod samples were very different from those observed for the Lake Greeson samples. As shown in Figure C77, the dissolved oxygen concentration declined over 2 mg/ℓ during the 10-day period. This is double the depletion observed in the Greeson samples. It is interesting to note that the trend of dissolved oxygen decline was essentially the same for samples from all three depths. As shown in the tabular data, moderately high concentrations of reduced iron, manganese, and nitrogen were present in the sample taken at a depth of 10 m. One would expect that the higher concentration of reduced chemical species would result in a higher oxygen consumption following aeration of the samples. This was not observed. The fact that dissolved oxygen consumption progressed at equal rates in samples which contained reduced chemical species as well as those which did not contain significant concentrations of reduced chemical species strongly suggests that reduced chemical species such as manganese II, iron II, and ammonia were not being oxidized in the BOD bottles.

99. The trend for total organic carbon (Figure C78) was not clear but, in general, only a small amount (if any) of the organic carbon was consumed during the 10-day incubation period. As discussed in the section covering the results from the Lake Greeson study, these data do not reflect any volatile organic matter which might have been present in these samples. Studies should be conducted to determine if volatile organic compounds are an important part of the organic carbon which is present in the tailwater system.

100. The rate of decrease of dissolved manganese (Figures C79 and C80) over the 10-day period was considerably faster in the Lake Nimrod samples than in the Lake Greeson samples. It was noted that there was considerably more particulate matter, some of which was hydrous oxides of iron, in the water

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from Lake Nimrod. The presence of this particulate matter may serve as a surface on which manganese could be adsorbed.

101. As with the Lake Greeson samples, relatively high concentrations of total and dissolved iron (Figures C81 and C82) were observed throughout the 10-day period. This is inconsistent with the expected chemistry of iron as well as the observations of what takes place in the tailwater. The detection of 1.5 mg/ℓ of iron apparently in solution even in the presence of 6 mg/ℓ of dissolved oxygen may indicate that the operationally defined "dissolved" iron was really not dissolved. The use of a filter with smaller pore size (0.1 μ) might resolve this discrepancy.

102. Changes in nitrogen species concentration during the 10-day incubation are shown in Figures C83 through C86. The nitrate nitrogen concentration remained essentially constant while the ammonia nitrogen concentration increased and total kjeldahl nitrogen (TKN) decreased. The concentration of organic nitrogen was computed by subtracting ammonia nitrogen from TKN. When this is done, the decrease in organic nitrogen is very pronounced. These data suggest that conversion of organic nitrogen to ammonia nitrogen (mineralization) was occurring during the period of incubation. Clearly, ammonia nitrogen oxidation is not occurring in the BOD bottles even in the presence of oxygen. It is also interesting to note that the conversion of organic nitrogen to ammonia nitrogen occurred at a similar rate for samples from all three depths. This process seems to be independent of the initial presence of higher concentrations of reduced chemical species in the sample from a depth of 10 m. Comparison of the nitrogen dynamics of the samples in BOD bottles with actual tailwater data (see Figures C75 and C76) suggests that different processes were occurring. This inconsistency is difficult to explain but may be related to the presence of some catalytic agent or the presence of bacteria on stream substrate that were absent in the BOD bottles.

103. As shown in Figure C87, there is a small increase in the sulfate concentration of the sample taken from 10 m throughout the period of incubation (0.05 mg/ℓ/km, r = 0.73). The odor of sulfide was present in the sample from 10 m. This increase probably reflects oxidation of the sulfide or reduced sulfur component to sulfate.

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Rough River Lake Study

Rough River Lake site description

104. Rough River Lake was designed and built by the Louisville District of the US Army Corps of Engineers. It was authorized by the Flood Control Act of 1938. Construction of the project was initiated in November 1955, and the project became operational in June 1961. Project purposes are to provide flood control, water supply, augmentation of low-flow conditions downstream in the interest of water quality, and to provide general and fish and wildlife recreation.

105. Rough River Lake is located in Breckinridge, Hardin, and Grayson Counties of central Kentucky. Rough River Dam is located on the Rough River at river mile 89.3 above its juncture with the Green River, 6 miles upstream of the Falls of Rough. The drainage area above the dam is 454 square miles.

106. Rough River Lake is located in the "Clifty" area of the Pennyroyal Region (a region denoting an area exceeding 11,000 square miles) of Kentucky. The lake is confined on the east by the Pennyroyal Plain which is formed on very thick, flat limestone beds. Both surface water and groundwater have caused solutioning in the limestone and created numerous sinks and caverns. The largest (in the world) and most important cave in the area is Mammoth Cave, having over 240 miles of mapped passageways.

107. Characteristics of Rough River Lake, which was formed by Rough River Dam, are summarized below.

Drainage area	454 square miles
Maximum flood control pool elevation	524 ft (NGVD)
Maximum flood control pool area	10,260 acres
Storage of flood control pool	3.046×10^5 acre-ft
Center-line elevation of penstock	432.5 ft (NGVD)
Bottom elevation at dam	427.7 ft (NGVD)

108. Rough River Dam is an earth core with rock-fill embankment with a crest width of 40 ft which provides a roadway for relocation of State Highway 110. The outlet is made up of a 12-ft-diam semielliptical reinforced concrete conduit and provides a discharge capacity of 3,000 and 5,580 cfs with the reservoir at conservation pool level (el 465) and spillway crest (el 524), respectively.

Rough River results

109. Figures C88 and C89 show the temperature and dissolved oxygen (respectively) distributions in Rough River Reservoir at a station located immediately upstream from Rough River Dam. Dissolved oxygen depletion was already present in early May of 1988. Anoxic conditions were present throughout the hypolimnion by late May. The dissolved oxygen profiles obtained on June 20 and June 28, 1988 show a marked dissolved oxygen maximum near the top of the thermocline. Although this dissolved oxygen maximum probably does not affect the Rough River tailwater, it is interesting from a limnological standpoint.

110. A small run-of-the-river dam used as hydropower for a grist mill and sawmill at the Falls of Rough in the early 19th century is located 11 km downstream from the Rough River Dam. This small dam creates a pooled reach which extended from the Falls of Rough Bridge upstream to Rough River Dam. The pooled reach creates an interesting study site because of the marked difference between the other field sites and was one of the reasons for choosing this tailwater as a study site. The elevation of the pool created by this dam coincides with the elevation of the base of Rough River Dam. The pool has a maximum depth of approximately 3 m. Discharge from the smaller dam (Falls of Rough) is made through two ports at a depth of approximately 2 m and from a surface spillway. At normal summer discharge rates, the pool above the Falls of Rough has a minimum of turbulence.

111. Sampling of the Rough River Lake tailwater began on August 16, 1988. Since Rough River is not a power generation project, releases were made on a continuous basis. The initial study was conducted at the low-flow conditions which were in place at the time of the study (approximately 20 cfs). On August 18 the discharge from Rough River Dam was changed to approximately 200 cfs. Time-of-travel and stream cross-section data were determined by WES personnel. Time of travel is plotted in Figure C90. At the higher flow conditions, the tailwater was sampled at time of travel plus 2 hr on August 17, 18, and 19. Steady-state sampling was conducted on August 19.

112. When the study was initiated, the impact of the Falls of Rough Dam was not clearly understood. For this reason, the samples taken at low-flow conditions were taken from the surface of the pool formed by the Falls of Rough Dam. Samples taken at time of travel plus 2 hr were also taken from the surface of this pool. After consulting with WES personnel, it was determined that water at a depth of from 1 to 2 m would be more representative of the

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water being released from the main dam. During the steady-state sampling which took place on August 19, samples were taken from a depth of 2 m or 0.5 m off the bottom when a depth of 2 m could not be obtained. The results of the three tailwater samplings are presented in Figures C91 through C104. The low-flow, steady-state sampling is indicated by "A," the high-flow, time-of-travel sampling by a "B," and the high-flow, steady-state sampling by a "C."

113. The complicating nature of the pool above the Falls of Rough Dam can easily be seen in the temperature data obtained at low-flow conditions (Figure C91). The temperature of water released from Rough River Dam was near 15° C. Warming occurs on the surface of the lower pool with a maximum temperature of 24° C being measured on the surface of the pool immediately upstream from the Falls of Rough Dam. Immediately below the Falls of Rough Dam, the temperature was only 20° C, reflecting the discharge from the lower levels of the pool. The cooler water released from Rough River Dam was apparently underflowing a warm layer which developed on the surface of the lower pool. Temperature and dissolved oxygen measurements made in the lower pool showed that the warm layer present was wedge-shaped, being thin at the upper end and thicker in the lower end. At the higher flow condition, most of this stratification disappeared and a mixed condition existed in the lower pool. This was substantiated by the fact that there were only minor differences in samples taken during the higher flow on the surface of the pool (high flow time-of-travel) and those taken from 1 to 2 m below the surface (high flow, steady state).

114. Dissolved oxygen was observed to decline in a downstream direction except for an increase which was observed immediately below the Falls of Rough Dam. This increase at the Falls of Rough Dam was probably due to the aeration which occurred as water fell over the small run-of-the-river dam and flowed over rocks immediately below the dam. Although the absolute values of dissolved oxygen at the low-flow conditions were lower than at high-flow conditions, the slope of the relationship between dissolved oxygen and distance was similar under both release conditions (Figure C92). All dissolved oxygen values are below saturation.

115. The Rough River system is considerably more alkaline than the Greeson or Nimrod sites as exhibited by the pH, specific conductance, and alkalinity plots of Figures C93 through C95, respectively. The alkalinity most likely is a result of the limestone beds of the Pennyroyal Plain. The higher pH tends to increase the rate of oxidation of reduced manganese and

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iron in laboratory studies (Stumm and Morgan 1970). The pH (Figure C93) tends to increase slightly in the downstream direction.

116. The distribution of specific conductance in the tailwater (Figure C.94) is consistent with removal of manganese from the system. The specific conductance of the Rough River tailwater is higher than that of Lakes Greeson and Nimrod. With higher "background" specific conductance, changes caused by such reactions as manganese removal will constitute a smaller percentage of specific conductance change than observed at Lakes Greeson and Nimrod. A similar situation exists for alkalinity. The alkalinity of the Rough River tailwater system (Figure C95) is higher than that observed at Lakes Greeson and Nimrod, consequently changes produced by reactions in the tailwater may be masked because of higher background conditions. Even with this condition, the alkalinity of the Rough River tailwater appears to decrease slightly in a downstream direction. As in the Nimrod tailwater, this decrease in alkalinity probably reflects acidity being added to the system from a reaction such as the oxidation of sulfide, iron, or manganese.

117. Total organic carbon (TOC) data (Figure C96) show a weak relationship with distance which is probably not significant (regression of time-of-travel sampling at high flow gives a value of $r = -0.64$ and a slope of -0.06 mg/ℓ/km). The weak relationship between TOC and distance may be due to the presence of volatile organic compounds in some of the samples. There is a decrease in TOC of approximately 2 mg/ℓ from Rough River Dam to the Falls of Rough. Below the Falls of Rough, there is a slight increase in TOC, possibly reflecting leaching or resuspension of organic carbon in the lower pool.

118. Turbidity in the Rough River tailwater (Figure C97) decreases in a downstream direction at low-flow conditions yet increases at high-flow conditions. The decrease at low-flow conditions is probably due to settling of particulate iron which forms after water enters the tailwater system. At higher flow, other factors such as resuspension of sediment probably explain the observed increase.

119. As shown in Figure C98, the trend for the sulfate concentration is to increase in a downstream direction. As suggested earlier, this increase is probably due to the oxidation of sulfide. An increase of approximately 2 mg/ℓ of sulfate occurs from Rough River Dam to station G. This increase would result from the complete oxidation of approximately 0.7 mg/ℓ of sulfide.

120. Only a small difference was observed between total and dissolved manganese (Figures C99 and C100) at downstream stations under high-flow

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conditions. The samples taken at low-flow conditions from the surface of the lower pool show manganese dropping to very low levels. This supports the suggestion that the main flow of water through this lower pool was as an underflow with the warmer surface layer being retained for an extended period of time. At the higher flow conditions, the manganese concentration appeared to be almost constant throughout the lower pool but began to decrease below the Falls of Rough. The lack of change through the lower pool probably occurred because of inefficient contact with stream substrate. Below the Falls of Rough, the stream consists of pools and ripples which result in more efficient contact of water with the stream substrate. Again, it should be pointed out that manganese removal may not reflect manganese oxidation.

121. Total and dissolved iron concentrations in the Rough River tailwater are shown in Figures C101 and C102, respectively. The reduced iron being released into the tailwater appears to be converted to the particulate form (assumed oxidized form) rather quickly. The downstream decrease in particulate iron (total minus dissolved) suggests settling of the iron floc as the major mechanism of removal. If this floc is the carrier for reduced sulfide (iron sulfide), the presence of particulate iron may be a good indicator of the presence of this chemical species.

122. Concentrations of nitrate nitrogen and ammonia nitrogen are shown in Figures C103 and C104, respectively. The results are similar to those observed in the Nimrod tailwater in that ammonia nitrogen decreased while nitrate increased. Also, as observed in the Nimrod tailwater, more ammonia nitrogen is removed from the system than appears as nitrate nitrogen, reflecting either denitrification or biological uptake.

123. The study of samples for the 10-day BOD study for Rough River Lake water was initiated on August 11, 1988. Samples were taken from depths of 3, 11, and 17 m. Sample replication was the same as that described for the Lake Greeson 10-day BOD study. The mean values for the triplicate analysis are summarized in Figures C105 through C115. These results indicate that the changes which occurred over the 10-day incubation period were very similar to those observed in the samples taken from Lake Nimrod with the exception of dissolved manganese. As shown in Figure C107, the total manganese concentration declined steadily through the 10-day incubation period but unlike the samples from Lake Nimrod, the dissolved component (Figure C108) decreased faster, indicating the presence of significant quantities of particulate manganese in the samples. Since the dissolved manganese which was removed from

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the system did not appear in the analysis for total manganese, it seems reasonable to conclude that the manganese was being adsorbed and/or precipitated onto the walls of the BOD bottles.

124. As in the Nimrod study, the presence of dissolved iron together with significant quantities of dissolved oxygen cannot be explained. The conversion of organic nitrogen to ammonia nitrogen without concurrent increases in nitrate nitrogen was also observed to occur in the Rough River Lake samples. The sulfate concentration in the Rough River tailwater increased throughout the incubation period with the largest increase being observed in the sample taken from 17 m. This suggests that oxidation of sulfide to sulfate was occurring in this sample.

Canyon Lake Study

Canyon Lake site description

125. Canyon Lake was authorized for construction under the River and Harbor Act approved 2 March 1945 and was modified by the Flood Control Act approved 3 September 1954. It was constructed by the US Army Corps of Engineers and is operated by the Fort Worth District. Construction of Canyon Lake Dam began in April 1958, and operation began in June 1964. It is a multipurpose project for flood control and water conservation with additional benefits of recreation and fish and wildlife habitats.

126. Canyon Lake is located on the Guadalupe River at river mile 303.3 about 16 miles northwest of New Braunfels, Comal County, Texas. The drainage area contributing to the reservoir is 1,432 square miles of watershed above the dam. The Guadalupe River originates in the Texas Hill Country on the Edwards Plateau, and is fed by streams and creeks whose pristine waters flow over limestone beds.

127. Characteristics of Canyon Lake, which was formed by Canyon Lake Dam, are summarized below.

Drainage area	1,432 square miles
Maximum flood control elevation	943 ft (NGVD)
Maximum flood control pool area	12,890 acres
Storage of flood control pool	3.464×10^5 acre-ft

Center-line elevation
of penstock   775 ft (NGVD)
Bottom elevation at dam   750 ft (NGVD)

128. The dam is an earthfill embankment with the maximum height at 224 ft above the stream bed. The flood control outlet structure is a 10-ft-diam conduit controlled by two 5-ft 8-in. by 10-ft hydraulically operated slide gates. The outlet structure is located in the main embankment approximately 1,600 ft to the right of the existing river channel.

129. The spillway is an uncontrolled broad-crested weir 1,260 ft long. It is located approximately 3,800 ft south of the flood control intake structure on the right bank. The crest of the weir is at el 943.

Canyon Results

130. The temperature and dissolved oxygen distributions in Canyon Reservoir throughout the summer of 1988 are summarized in Figures C116 and C117. The dissolved oxygen distribution in Canyon Lake showed the development of a metalimnetic dissolved oxygen minima near the top of the thermocline. This same feature has been observed in several reservoirs in Arkansas and other states in the southeastern part of the United States (Nix 1981). By September, anoxic conditions were present throughout the entire hypolimnion.

131. Historic data on Canyon Reservoir (Hannan and Broz 1976) indicated that the concentration of reduced iron and manganese had been relatively low in previous years. This may be due, in part, to the fact that the Guadalupe River drains limestone terrain which results in alkalinities and pH values which are significantly higher than systems where limestone is absent or minimal. The higher pH values present in Canyon Lake and tailwater probably prevent the concentration of iron and manganese from increasing to the levels observed in Rough River Lake and Nimrod Lake. For this reason and because of limited time and funding constraints, it was determined not to conduct a full-scale study of the Canyon tailwater. However, a modified study was conducted on September 19, 1988. No alteration of the discharge rate was requested. The discharge from Canyon Reservoir was approximately 114 cfs during the study. Samples were obtained and processed at the established tailwater stations and shipped via Air Express to the OBU Laboratory. Holding time for these samples did not exceed 24 hrs.

132. The results of this study are given in Figures C118 thorough C125. As shown in Figure C118, there is downstream warming of the Canyon tailwater. Dissolved oxygen, which was below saturation, showed a slight decline

throughout the region of the tailwater which was studied. This decline was probably related to the decrease in saturation limits associated with downstream warming. The pH also increased in a downstream direction, probably in response to a loss of free carbon dioxide from the system. A change in the specific conductance at the downstream tailwater stations was not observed. As discussed above (Rough River Lake tailwater), the background specific conductance was high enough to mask any changes which would have resulted from precipitation of such components as iron and manganese.

133. The inverse relationship between nitrate nitrogen and ammonia nitrogen is shown in Figure C122. Unlike the other tailwaters which were studied, nitrogen appears to be conserved in this system. Although low, the concentrations of both total and dissolved manganese (Figure C123) were observed to decline throughout the section of the tailwater which was studied. Only small differences in the concentration of total and dissolved manganese were observed. Dissolved iron was below detection limits in the tailwater while total iron seemed to show a small decline in the first 13 km of the tailwater. There is only a suggestion of increased sulfate in the first 9 km of the Canyon Lake tailwater, but the background of sulfate is relatively high. Therefore, the small increases in sulfate which would be expected from the oxidation of sulfide were probably masked. It should be noted that the odor of hydrogen sulfide was present in the upstream section of the Canyon Lake tailwater during this study.

134. Late in this study, a reference for an analytical technique (Hongzhang 1982) which may be useful in studying sulfide in tailwater systems was furnished by WES personnel. This method involved the titration of water with mercuric nitrate and is reported to be useful in the $\mu g/\ell$ region. This method was used to determine sulfide in the Canyon Lake tailwater on September 21, 1988. The concentration at station A was found to be 40 $\mu g/\ell$ but declined to background values at station B and all other downstream stations. As discussed earlier, this method probably does not detect particulate sulfide which may be present.

PART IV: SUMMARY

135.   Water quality data were obtained from four tailwater systems which originate from the hypolimnion of four Corps of Engineers reservoirs.   These data were obtained to evaluate chemical reactions which occur following the introduction of oxygen into the tailwater system.   Of particular interest were reduced chemical components which have the potential to consume dissolved oxygen.   The data indicated that there were numerous factors involved in the oxidation reactions which must be understood if meaningful modeling and management of these systems are to be accomplished.   A study of the changes in water quality of the tailwater from its origin to several downstream locations was used to obtain information on the chemical dynamics of tailwater systems. The results obtained from this study indicate that many of the water quality changes which occur in a tailwater system are rather complex and that additional study is necessary in order to fully understand many of the observed chemical changes.

136.   A summary of the observed changes in the concentration of selected chemical components is given in the following paragraphs.   A more detailed analysis of the chemodynamics is addressed in a subsequent report.

137.   Dissolved oxygen.   An increase in dissolved oxygen in a downstream direction was observed only at the Greeson tailwater.   At the other sites, the dissolved oxygen generally decreased in the downstream direction.   This observation is consistent with the fact that loading of reduced species was considerably higher at the other sites.   Greeson was the only site with a hydropower release; thus, the dissolved oxygen level at the beginning of the tailwater was much lower than at the other sites, which experienced considerable reaeration through the release structure.   Additionally, downstream warming was greater at the other sites, lowering dissolved oxygen saturation.

138.   Iron.   The concentration of dissolved iron in the hypolimnion of Lake Nimrod and Rough River Lake was in excess of 3 mg/ℓ at the time of the study.   The data from the tailwaters of these two reservoirs indicate that oxidation of iron was occurring in the first 100-200 m of the tailwater.   The oxidation product was probably a hydrous oxide of iron and it appeared throughout the upstream section of these tailwaters as a visible floc.   The oxygen demand caused by dissolved iron appears to be exerted very quickly and is probably not a factor in the oxygen dynamics of the stream below the first few hundred meters of the tailwater.   It should be noted that the oxidation of

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iron II to iron III results in liberation of hydrogen ions into the system. The presence of hydrous oxides of iron in the tailwater accounts for most of the turbidity found below Nimrod and Rough River Lakes.

139. Manganese. Although oxidation rates of manganese II to manganese IV have been observed to be very slow by numerous investigators, removal of the reduced form of manganese from all of the tailwaters studied occurred over the first 10 to 15 km of the tailwater. Unlike iron, the amount of particulate manganese present in the tailwater was relatively low. The presence of manganese-oxide-coated gravels in each of the tailwaters studied suggests that the ultimate fate of manganese introduced into the system is coatings on stream substrate rather than a floc or suspension as in the case of iron. Using the mechanism proposed by Stumm and Morgan (1970), it is suggested that manganese is being removed from the tailwater by adsorption onto stream substrate but this removal probably does not constitute oxidation. The mechanism proposed by Stumm and Morgan suggests that the adsorption proceeds quickly but the subsequent oxidation is slow. If this is the case, using the decrease in concentration of dissolved manganese in the tailwater to indicate manganese which has been oxidized is not correct. If earlier measurements of the rate of the actual oxidation step are correct, the oxidation reaction may be too slow to significantly affect the dissolved oxygen dynamics of the stream. Additional experiments are needed to clarify the impact of adsorption of manganese onto stream substrate.

140. Sulfide and sulfate. The analytical chemistry of sulfide in tailwater presents a difficult analytical problem. Sulfide may exist in a dissolved form (sulfide or bisulfide ion) or as particulate sulfides such as iron sulfide. Both have the potential to be oxidized and impact the dissolved oxygen dynamics of a tailwater system. The sulfide system is further complicated by the fact that hydrogen sulfide can be removed from the tailwater system by degassing as well as oxidation. When sulfide was added to hypolimnetic water from Lake Nimrod, no sulfide could be detected until a breakthrough point had been reached. This strongly suggests that iron sulfide was being precipitated in the sample. It is likely that as iron is oxidized and precipitated in the first 100-200 m of the tailwater, insoluble iron sulfide was coprecipitated along with the hydrous oxides of iron. As discussed above, this floc remained in suspension some distance downstream. If this was occurring, the particulate iron sulfide can be expected to exert an oxygen demand as long as it is present. This would mean that the impact of sulfide

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on the tailwater would be experienced much further downstream than if it were present only in a soluble form. The suggestion that particulate iron sulfide (coprecipitated on the hydrous oxides of iron) was being oxidized in the tailwater is supported by the observation that an increase in sulfate concentration was observed downstream from the Nimrod and Rough Rivers. If it can be assumed that the addition of sulfate from tributaries and groundwater systems is minimal, it is suggested that the increase in sulfate concentration be used to estimate the quantity of sulfide which has been oxidized in each of the tailwater systems. The possibility that other reduced sulfur compounds (such as dimethyl sulfide) were present and contribute to the oxygen dynamics of the system has not been eliminated.

141. Nitrogen. An inverse relationship between ammonia nitrogen and nitrate nitrogen was observed at Nimrod, Rough River, and Canyon Lakes. The concentration of ammonia nitrogen in the Lake Greeson tailwater was too low to make an evaluation of a trend. The ammonia which was introduced into the tailwater from the anoxic hypolimnion would be expected to exert an oxygen demand as it entered the tailwater system. There is little doubt that the conversion of ammonia to nitrate was occurring but the observation that nitrogen was not conserved in the transition suggests that more is involved than a simple oxidation reaction. Nitrogen transformations which can take place in streams and sediment have been summarized by Reddy and Patrik (1984). It is likely that the lack of conservation of nitrogen in the transition from ammonia to nitrate is due to either denitrification (probably taking place in bottom muds) or biological accumulation. Obviously the maximum oxygen demand exerted by ammonia can be estimated by the decrease in ammonia concentration which occurred throughout the section of the tailwater which was studied. The actual oxygen demand caused by ammonia may be considerably less than the observed decrease in concentration since direct utilization of ammonia by biota cannot be ruled out. If denitrification was taking place in the system, the ammonia must first be oxidized to nitrate followed by a series of reactions in stream sediment which would result in the loss of nitrogen gas or an oxide of nitrogen. If the latter is occurring, the observed decrease in ammonia concentration throughout the section of the tailwater which was studied would be the best estimate of oxygen demand created by this species.

142. Organic carbon. A decrease in TOC in a downstream direction was observed at Lake Nimrod and Rough River Lake. The decrease was considerably more pronounced at Rough River Lake. Even though the general trend for TOC

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was to decline downstream, there was considerable fluctuation in these data. A review of the variations between replicated samples in this laboratory suggests that the variations observed in the Rough River tailwater are real. The stoichiometry of oxygen consumption by organic carbon clearly indicates that it is a very important factor in the dissolved oxygen dynamics of a stream. Since the water being introduced into the tailwater system is originating from an anoxic environment, various reduced forms of organic carbon are likely to be present. Some of these reduced forms of organic carbon are probably easily oxidizable and thus very important in the dissolved oxygen dynamics of the tailwater system. Others may be resistant to oxidation or have a rate of oxidation which is extremely slow. The nonspecific determination of TOC does not distinguish between these two groups. If the percent of easily oxidizable organic carbon is low compared to the more resistant compounds, it may be difficult to determine changes which occur in the tailwater system with the needed degree of precision. In addition, one cannot rule out the possibility that volatile organic compounds may be present in the water which was introduced into the tailwater system. The ampulation method for determining organic carbon requires a period of purging with nitrogen prior to sealing of the ampule. Volatile organic compounds would be removed in this step of the determination. Additional work is needed to evaluate the various groups of organic compounds which are present in anoxic hypolimnetic water in order to develop analytical methodology which could be used to evaluate oxidation of organic matter in the tailwater system.

143. <u>Ten-day BOD.</u> The results from the 10-day incubation studies which were conducted with water from Greeson, Nimrod, and Rough River Lakes indicate that some oxygen consumption was taking place in the samples, but the specific component(s) which were responsible for the consumption were not identified. The fact that the operationally defined dissolved iron component remained high throughout the 10-day incubation period is inconsistent with the reactions which were observed in the tailwaters. Manganese removal rates were much slower than observed in the tailwater and ammonia nitrogen increased rather than decreased as observed in the tailwaters. The fact that seeded BOD determinations (Appendix A) of the Lake Nimrod and Rough River Lake tailwater samples showed that relatively rapid oxygen consumption was occurring suggests that the presence of bacteria as well as factors such as exposure to stream substrate and turbulence may play an important role in the rate at which oxidation reactions occur in the tailwater systems. Additional work is needed to

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evaluate the role of bacteria, stream substrate, and turbulence on the oxidation reactions occurring in these systems.

144. pH and free CO_2. Free carbon dioxide was observed to increase with depth at Greeson, Nimrod, and Rough River Lakes. The concentration of free carbon dioxide in the hypolimnion of these lakes was consistent with the dissolved oxygen depressed or depleted condition which existed at the time of sampling. The presence of free carbon dioxide in concentrations above that which would be expected with aerated water in equilibrium with the atmosphere results in a decrease in pH. When this water is introduced into the tailwater, excess free carbon dioxide should be removed rather quickly through an outgassing process. Theoretically, an increase in pH would accompany the release of excess carbon dioxide. This pattern was observed in the Lake Greeson tailwater, but the patterns observed at Nimrod and Rough River Lakes were not clear. It is possible that the expected increase in pH caused by a loss of excess carbon dioxide may be countered by reactions which would result in a lowering of pH; for example, the oxidation of reduced iron, manganese, or sulfide. This is consistent with the observation that the expected trend (increase in pH and decrease in free carbon dioxide) was observed in the Lake Greeson tailwater where iron and manganese concentrations were low while the trend at Rough River and Nimrod Lakes (where iron and manganese were higher) was less defined. The rather obvious increase in pH which was observed in the Canyon tailwater is probably due to both the loss of free carbon dioxide and continued reaction with the carbonate substrate of the stream.

PART V: RECOMMENDATIONS

Analytical Methods

145. The presence of reduced chemical species in tailwaters requires
that special attention be given to the transient chemical nature of the system
which may be present. The concentration of chemical constituents which can be
altered following the introduction of dissolved oxygen or which can be lost in
the gas phase can change rapidly. Ideally, one would want to conduct all
chemical analysis at or very near the collection site in order to minimize
these changes. This is not practical since some of the instrumentation neces-
sary to conduct the analysis is not well-suited for field use. For most
parameters, the treatment of samples in a manner designed to preserve selected
chemical components is the method of choice.

146. Field determination of some parameters is required since preserva-
tion is very difficult, if not impossible. Obviously temperature and dis-
solved oxygen must be measured at the sampling site. If Winkler titration is
used for dissolved oxygen rather than an electronic system, proper preserva-
tion will allow fixed samples to be transported to a laboratory prior to the
actual titration.

147. The specific conductance, free carbon dioxide, and the pH of sam-
ples must also be determined at or very shortly after the collection of the
samples. In tailwaters which originate in the hypolimnion of a stratified
lake, the free carbon dioxide concentration begins to change as soon as it is
exposed to the atmosphere. This loss of free carbon dioxide results in a pH
change, thus the field measurement of pH is required. The major factor
affecting the specific conductance of tailwaters (excluding the effect of
tributaries and groundwater) is probably the loss of iron and manganese due to
precipitation or absorption. For this reason, specific conductance should be
measured at or near the sampling site.

148. In order to evaluate the concentration of reduced iron and manga-
nese in the tailwater, it is necessary to operationally define these parame-
ters. It is assumed that reduced iron and manganese will pass through a
0.45-μ filter. Using this definition, a small portion of a sample can be
filtered at the sampling site and then acidified to prevent precipitation.
There is some suggestion that very small particulate iron may pass through the
0.45-μ filter. The use of a 0.1-μ filter would reduce the probability that

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particulate forms of these metals would pass the filter but the fact that using a 0.1-μ filter requires additional time for the filtration process may cancel out any benefits. A comparison of results using the two filters would be useful in determining which should be used. A portion of unfiltered sample can be acidified and retained for iron and manganese analysis. According to the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation (1985), the determination of total iron and total manganese requires that an unfiltered sample be subjected to an acid digestion prior to the determination of the metals. This is not recommended for the study of tailwaters since the particulate iron present as oxidation products of these metals remains soluble in the acidified sample. The acid digestion would introduce iron and manganese, which are part of the silicate structure of sediment material. Since the iron and manganese which are of interest in the tailwater are already dissolved or recently precipitated, there is no need to conduct the acid digestion. The method of choice for the determination of iron and manganese in acidified samples (filtered and unfiltered) is atomic absorption spectrometry.

149. The ammonia nitrogen and nitrate nitrogen also have the potential to change rapidly. Acidification of a sample with sulfuric acid was adequate to preserve the ammonia in a sample for a period long enough to allow transportation to a laboratory for subsequent determination using a specific ion electrode or colorimetric method with comparable sensitivity. Preservation of nitrate nitrogen is more difficult and its determination near the sampling site will give the best results. In this study, nitrate nitrogen was determined in the field laboratory using an ion chromatograph method. If ion chromatography is not available, a field colorimetric determination of nitrate is recommended. Depending on the chemical nature of some tailwaters, preservation for subsequent nitrate nitrogen analysis may be practical. This should be verified before relying on preservation for the nitrate nitrogen analysis.

150. Since sulfate is a potential product of reduced sulfur compounds which may be present in tailwaters, it is recommended that it be determined as soon after collection as possible. The problems encountered with the analysis of sulfide in tailwater systems have been discussed in this report. There appears to be some difficulty with determining the total sulfide present if iron is also present. Additional work is needed to evaluate methodology in this area.

151. Turbidity should also be determined at or near the sample collection site. The oxidation of iron can contribute to the turbidity. Storing a sample for later turbidity determination is not practical since acidification would result in the dissolving of some of the particulate matter.

152. It is recommended that a program for the evaluation of the chemistry of tailwaters receiving water from an oxygen-depressed hypolimnion be made after some initial studies have been conducted to determine the range of concentration of components which can be expected. After the initial evaluation, a procedure for sample handling, preservation, and analysis can be established.

Further Research

153. This study has provided information on the concentration of selected chemical parameters on four tailwaters. Attention has been given to such matters as appropriate analytical methods and sampling preservation techniques. The results have demonstrated how some of these parameters change throughout the downstream section of the tailwater. A full understanding of the processes which produce the observed changes is still lacking. Of particular importance are questions such as:

    a. What is the actual mechanism of iron and manganese removal from the tailwater?

    b. What are the specific organic compounds which contribute to the oxygen demand in such a system?

    c. What is the role of sulfide or iron sulfide in the dissolved oxygen consumption processes occurring in the stream?

    d. What are appropriate analytical techniques for measuring total sulfide and iron sulfide in tailwaters?

    e. What is the nature of benthic demand in the tailwater? (Refer to Appendix A.)

    f. Is introduction of aerobic bacteria a rate-determining step in the oxidation of reduced chemical species in the tailwater? (Refer to Appendix A.)

154. It is also recommended that some attention be given to the situation which exists at Lake Nimrod and the Nimrod tailwater. The findings reported in this study suggest that introduction of reduced chemical species (especially iron) into the epilimnion results in the production of very turbid water. The precipitation of iron was also identified as the main contributor to turbidity in the tailwater during certain periods of the year. There is a

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need to study this system further to determine if these processes are occurring and if so, to explore operational and/or structural changes which could significantly improve the water quality both in the lake and in the tailwater.

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Table 1

Distance and Time of Travel Between Stations at Lake Greeson Study

Segment	River Miles	Travel Time Between Stations t, hr min
Dam-A	105.8-105.7	0:05*
A-B	105.7-105.3	0:21
B-C	105.3-103.4	1:41
C-D	103.4-100.2	3:07
D-E	100.2-99.2	1:40
E-F	99.2-94.4	9:20

* Estimated travel time between dam and station A.

Table 2

Distance and Time of Travel Between Stations at Lake Nimrod Study

Segment	River Miles	Travel Time Between Stations t, hr:min
A-B1	62.6-62.0	1:48
B1-B2	62.0-61.4	2:18
B2-B3	61.4-60.8	1:06
B3-C	60.8-59.7	3.36
C-D	59.7-58.0	9:12

Note: Station A is at the dam.

Table 3

Distance and Time of Travel Between Stations at Rough River Study

Segment	River Miles	Travel Time Between Stations t, hr:min
Dam-A	89.4-89.2	:20*
A-A1	89.2-88.4	2:20
A1-B	88.4-87.7	3:10
B-C	87.7-86.3	6:45
C-D	86.3-84.3	11:30
D-E	84.3-83.0	5:45
E-F	83.0-80.2	5:00
F-G	80.2-78.4	6:15

* Estimated travel time between dam and station A.

Table 4

Distance and Time of Travel* Between Stations at Canyon Study

Segment	River Miles	Travel Time* Between Stations t, hr:min
Dam-A	303.0-302.0	1:25
A-B	302.0-301.2	1:10
B-C	301.2-299.7	2:19
C-D	299.7-296.8	3:59
D-E	296.8-294.0	4:04
E-F	294.0-292.1	2:35

* Estimated travel times for Canyon.

Table 5

Preservation Methods Used on Subsample Aliquots

Aliquot A - 30 ml in polyethylene bottle, filtered through a 0.45-μ filter, acidified to pH 2 with nitric acid

Aliquot B - 30 ml in polyethylene bottle, acidified to pH 2 with nitric acid

Aliquot C - 500-ml polyethylene bottle, held at 4° C

Aliquot D - 500-ml polyethylene bottle, acidified to pH 2 with sulfuric acid

Aliquot E - 100-ml polyethylene bottle, filtered through a glass fiber filter, held at 4° C

Aliquot F - 30-ml glass bottle acidified to pH 2 with sulfuric acid, held at 4° C

Aliquot G - 30-ml glass bottle filtered through a pre-combusted glass fiber filter, acidified to pH 2 with sulfuric acid, held at 4° C

Table 6

Parameters and Methods Used for Analysis in the Field

Parameter	Aliquot	Method and Reference
pH (field and lab)	in situ and C	Electrometric (American Public Health Association, AWWA, FPCF 1985
Alkalinity	C	Electrometric titration EPA 310.1 (US EPA 1979)
Sodium	A	Flame AA, EPA 273.1 (US EPA 1979)
Potassium	A	Flame AA, EPA 258.1 (US EPA 1979)
Calcium	A	Flame AA, EPA 215.1 (US EPA 1979)
Magnesium	A	Flame AA, EPA 242.1 (US EPA 1979)
Iron	B (total) A (filtered)	Flame AA, EPA 236.1 (US EPA 1979)
Manganese	B (total) A (filtered)	Flame AA, EPA 243.1 (US EPA 1979)
Chloride	E	Ion chromatography (Waters 1985)
Sulfate	E	Ion chromatography (Waters 1985)
Total inorganic carbon	E	Ion chromatography (Waters 1985)
Nitrate-nitrogen	E	Ion chromatography (Waters 1985)
Nitrite-nitrogen	E	Ion chromatography (Waters 1985)
Ammonia-nitrogen	D	Specific ion electrode EPA 350.3 (US EPA 1979)
Total Kjeldahl nitrogen	D	Digestion, EPA 341.1, modified for manual determination (US EPA 1979)
Total phosphorus	D	Persulfate digestion, spectrophotometric, EPA 365.4, modified for manual determination (US EPA 1979)
Soluble reactive phosphorus	E	Spectrophotometric, EPA 365.4, modified for manual determination (US EPA 1979)
Total organic carbon	F and G	Ampulation, persulfate digestion, EPA 415.2 (US EPA 1979)
Turbidity	C	Nephelometric (American Public Health Association, AWWA, and FPCF 1985)

Table 7

Mean and Standard Deviation for Data Obtained at
Greeson Tailwater Station B on 7/28/87

Parameter	Mean	Standard Deviation
Temperature (° C)	14.00	0.500
pH	6.25	0.090
Sp. cond. (μsec)	25.50	4.900
Nitrate nitrogen	0.18	0.020
Ammonia nitrogen	0.01	0.009
Total manganese	0.06	0.006
Total iron	0.13	0.020

Table 8

Mean and Standard Deviation for Data Taken at
Greeson Tailwater Station A on 9/12-14/87

Parameter	Mean	Standard Deviation
Temperature (° C)	14.10	0.30
Dissolved oxygen (mg/ℓ)	4.60	0.20
pH	6.15	0.21
Sp. cond. (μsec)	33.00	0.50
Alkalinity (mg/ℓ)	9.00	4.00
Turbidity (NTU)	1.00	0.20
Nitrate nitrogen (mg/ℓ)	0.17	0.01
Total iron (mg/ℓ)	0.07	0.02
Total manganese (mg/ℓ)	0.10	0.02
Sulfate (mg/ℓ)	2.60	0.10
Chloride	1.60	0.10

Table 9

Correlation Coefficients and Slopes for Regression of
Data from Greeson Tailwater Station A with Time

Parameter	r	Slope
Temperature	-0.09	-0.002 °C/hr
Dissolved oxygen	0.44	0.007 mg/ℓ hr
Nitrate nitrogen	0.29	0.0002 mg/ℓ hr

Table 10

Comparison of Sampling at Greeson Tailwater, 9-12-87 to 9-14-87

Parameter	Correlation Coefficient		Slope		Intercept	
	Time of Travel	Steady State	Time of Travel	Steady State	Time of Travel	Steady State
Temperature	0.83	0.97	0.100	0.100	14.20	13.40
Dissolved oxygen	0.86	0.85	0.200	0.100	5.40	5.70
pH	0.92	0.79	0.030	0.020	6.20	6.10
Dissolved manganese	-0.98	-0.91	-0.004	-0.002	0.09	0.08

APPENDIX A: OXYGEN CONSUMPTION STUDIES

Preliminary Oxygen Consumption Studies
Lake Greeson Tailwater and Inpool

1. An attempt was made to use the standard light-dark bottle technique to investigate dissolved oxygen consumption in the Lake Greeson tailwater. On August 12 and 13, 1987, samples were taken from selected stations in the tail-water and placed in standard biochemical oxygen demand (BOD) bottles. Six of the samples were in clear BOD bottles and six in dark BOD bottles. Two of the dark bottle samples were poisoned using 10 g of phenol. The initial dissolved oxygen concentration of each bottle was determined with a Yellow Springs Dissolved Oxygen Analyzer which was calibrated using a standard Winkler titration. The bottles were placed back into the river in approximately 0.5 m of water beginning at 1000 hr where they remained until 1400 hr when they were removed and the final dissolved oxygen concentration determined. The results of this study are summarized below:

Type of Bottle	Initial DO mg/ℓ	Final DO mg/ℓ	Change mg/ℓ
Station A (8/12/87)			
Light bottles			
A	6.4	6.3	-0.1
B	6.3	6.3	0.1
C	6.3	6.2	-0.1
D	6.3	6.4	0.1
E	6.3	6.2	-0.1
F	6.4	6.2	-0.2
Mean			-0.05
Standard deviation			0.12
Dark bottles			
A	6.1	6.1	0.0
B	6.3	6.5	0.2
C	6.3	6.4	0.1
D	6.3	6.3	0.0
Mean			0.08
Standard deviation			0.10
E(phenol)	5.8	5.5	0.4
F(phenol)	5.9	5.2	0.7
Mean			0.55
Standard deviation			0.21

Type of Bottle	Initial DO mg/ℓ	Final DO mg/ℓ	Change mg/ℓ

Station F (8/13/87)

Light bottles

A	6.9	7.0	0.1
B	7.2	7.0	-0.2
C	7.4	7.2	-0.2
D	7.3	7.3	0.0
E	7.5	7.3	-0.2
F	7.3	7.2	-0.1
Mean			-0.10
Standard deviation			0.13

Dark bottles

A	7.2	7.0	-0.2
B	6.8	7.1	0.3
C	6.9	6.7	-0.2
D	7.1	6.9	-0.2
Mean			-0.08
Standard deviation			0.25
E(phenol)	6.7	6.9	0.2
F(phenol)	6.6	6.5	-0.1
Mean			0.05
Standard deviation			0.21

2. Essentially no significance can be given to the results except to conclude that the BOD of the Greeson tailwater was extremely low. This study did not provide any information which could be used in evaluating the dissolved oxygen consuming processes occurring in the Greeson tailwater. It should be noted that the concentration of reduced chemical species in the tailwater was very low during this study.

3. Oxygen consumption studies for the in-pool station at Lake Greeson were also conducted using the Gilson Differential respirometer. Samples were collected at three depths (epilimnion, metalimnion, and hypolimnion) with averaged triplicate values representing each time, depth, and treatment. Results from the Gilson respirometer indicated that there was a discrepancy when compared to those obtained with the light and dark bottles and BOD methods. These differences could be due to several reasons:

<u>a</u>. The respirometer uses carbon dioxide evolution to measure oxygen uptake, and if a system releases levels above microbial respiration production, an abnormally high reading could be obtained.

<u>b</u>. Also, the Gilson respirometer is a laboratory-based instrument that is more sensitive to oxygen consumption changes than either the light and dark bottle or BOD method.

<u>c</u>. In addition, the respirometer has a vigorous shaking system that creates ideal conditions for cellular respiration.

For these reasons, it was decided that the respirometer results were of no value to this study for measurement of oxygen consumption in the inpool samples.

Benthic Oxygen Demand

4. The benthic oxygen demand (i.e., sediment oxygen demand, SOD) was estimated at one sampling station in the Lake Nimrod and Rough River Lake tailwaters. This was accomplished using a benthic respirometer which consisted of a 27-cm section of Plexiglas cylinder with a diameter of 34 cm. The top of the cylinder was closed with Plexiglas and was fitted with a Yellow Springs dissolved oxygen (DO) probe. The sensing end of the probe extended 3 cm into the chamber. The chamber was also fitted with a magnetic stirrer which provided the necessary stirring in the vicinity of the DO probe and which produced sufficient mixing to circulate water throughout the chamber. At each site, the respirometer was placed on the bottom muds, resulting in a volume of 20.0 ℓ of water in the chamber. The DO probe had a cable length sufficient to reach the bank where it was connected to a Yellow Springs DO meter.

5. The DO probe was calibrated immediately prior to the beginning of each experiment. It was also calibrated at the end of each experiment to insure that there had been no drift of the instrument.

6. On July 19, 1988, the respirometer was deployed at a location immediately upstream from station B1 of the Nimrod tailwater. This section of the stream had a depth of approximately 1 m and current was barely detectable. The bottom throughout this section of the stream consisted of a mixture of rock and muds. Since it was necessary to insert the respirometer into bottom muds, a location where there were only minimal rocks had to be chosen. The experiment was initiated at 1200 hr and continued until 1600 hr. Periodic

measurements of the dissolved oxygen concentrations were made throughout the 4-hr period. The results of these measurements are given in Table A1.

Table A1

Concentration of DO in Benthic Respirometer

Nimrod Tailwater (station B1) 7/19/88

Time	D.O. (mg/ℓ)
1200	4.5
1215	4.2
1230	3.8
1300	3.5
1330	3.2
1400	3.1
1430	3.1
1500	3.0
1530	3.0
1600	2.9

7. On August 19, 1988, a similar experiment was conducted at station C in the Rough River Lake tailwater. It should be noted that the location of this study was within the pool formed by the Falls of Rough Dam. The depth of the water at the site was 2 m and the bottom consisted of mud and leaf litter. The study was initiated at 1400 hr and continued until 1700 hr. The results of this study are given in Table A2.

Table A2

Concentration of DO in Benthic Respirometer

Rough River Lake (Station C) 8/19/88

Time	D O. (mg/ℓ)
1400	5.2
1415	5.0
1430	4.9
1445	4.7
1500	4.6
1515	4.5
1530	4.4
1545	4.3
1600	4.2
1615	4.1
1630	4.1
1645	4.1
1700	4.1

8. The concentration of dissolved oxygen in the chamber of the respiro-meter as a function of time is shown in Figures A1 and A2 for the Nimrod and Rough River tailwaters, respectively. It is interesting to compare the rate of oxygen depletion which was observed in the 10-day BOD study with that observed in the benthic respirometer. The dissolved oxygen concentration of the samples obtained from a depth of 10 m in Lake Nimrod declined at a rate of 0.01 mg/ℓ/hr. The observed rate of decline of dissolved oxygen in the benthic respirometer was approximately 0.4 mg/ℓ/hr. The benthic demand is consider-ably higher than the demand exerted by "in-water" processes. Adjusting for the volume of water in the respirometer, a total of 8.0 mg of oxygen was con-sumed by 0.091 m^2 of bottom area per hour, or an SOD of 2.11 g O_2/m^2/day. This value of SOD is reasonable compared with measurements in other systems (Hatcher 1986).* However, the measurement should have extended over several days, rather than several hours, to better define the SOD.

9. Numerous investigators have measured SOD (Hatcher 1986) in a vari-ety of environments but there is much controversy over their proper measuring technique to yield a true snapshot of the SOD. Results depend on the rate of mixing (i.e., flow velocity) within the chamber (Whittemore 1986). More work is needed in determining an accurate method for measuring SOD that is representative of oxygen demand exerted in the flowing system.

10. As described in the section of this report dealing with the dynamics of iron and sulfur in the tailwater system, the deposition of iron sulfide or other reduced chemical species in bottom muds may account for higher benthic demands than in nontailwater streams. Clearly, additional work on the nature of benthic demand is needed for the tailwater stream.

Seeded BOD Studies

11. Standard 5-day BOD determinations were conducted on selected sam-ples from the tailwaters of Greeson, Nimrod, and Rough River Lakes. The results of these determinations are given in Table A3.

12. A comparision of these data with the 10-day incubation study shows that the presence of the seed material made a significant difference in oxygen consumed in the samples from the Nimrod and Rough River tailwaters but not in the ones from the Greeson tailwater. This suggests that the observation of

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* See References at the end of the main text.
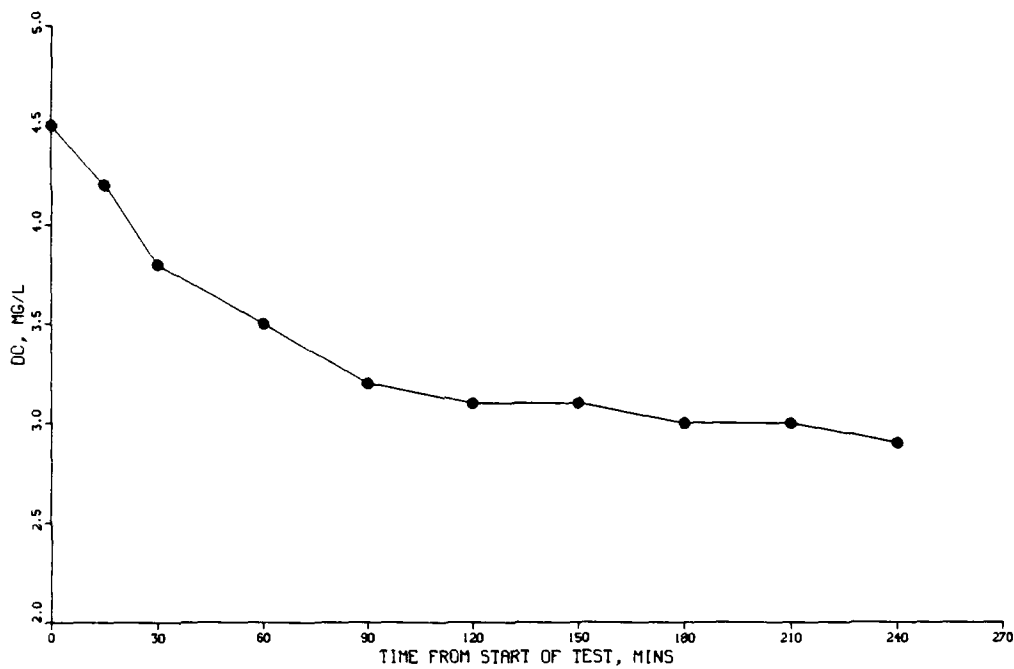
Figure A1.   Benthic respirometer readings at
Nimrod tailwater, July 19, 1988
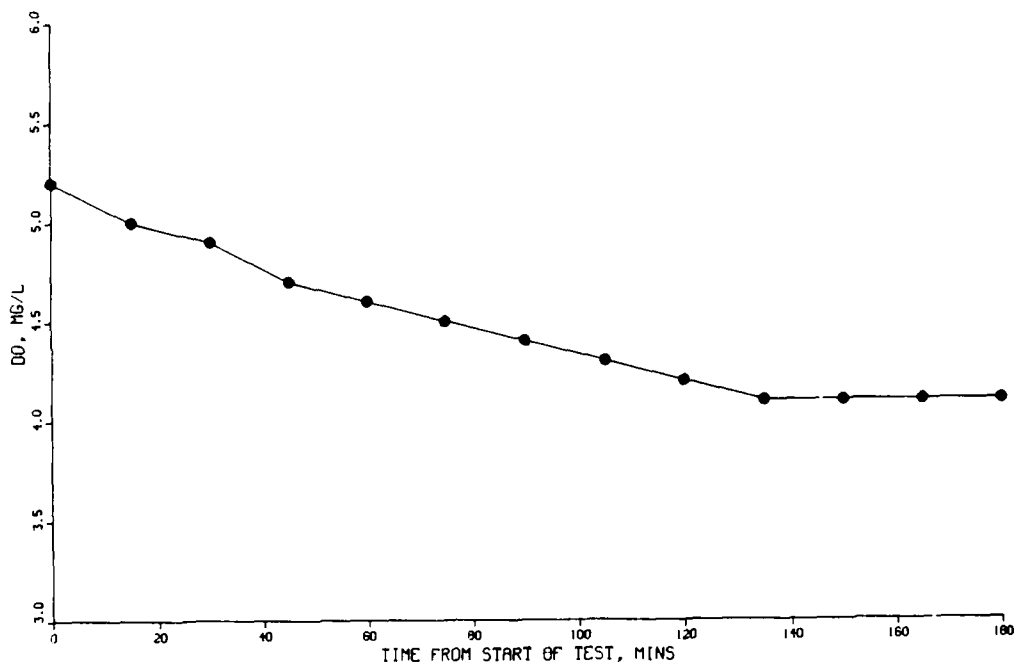
Figure A2.   Benthic respirometer readings at
Rough River tailwater, August 19, 1988

Table A3

Standard 5-day BOD for Greeson, Nimrod,

and Rough River Tailwaters

Site	BOD mg/ℓ
Greeson tailwater (8/17/87)	
Station B	1.0
	0.7
	0.8
	0.7
	0.8
	0.8
Mean	0.80
Standard deviation	0.35
Nimrod tailwater (7/5/88)	
Station A	4.9
	4.3
	4.3
Mean	4.5
Standard deviation	0.35
Station B	4.6
	4.0
	4.2
Mean	4.3
Standard deviation	0.31
Station B1	6.4
	6.1
	5.9
Mean	6.2
Standard deviation	0.25
Rough River tailwater (8/12/88)	
Station A	>7.5
	>7.6
	>7.5
Mean	>7.5
Rough River tailwater (8/12/88)	
Station C	>6.9
	>6.8
	>6.7
Mean	>6.8

(Continued)

A9

Table A3 (Concluded)

Site	BOD mg/ℓ
Rough River tailwater (Cont'd)	
Station E	>6.9
	>6.9
	>6.8
Mean	>6.9

little oxidation of ammonia and iron during the 10-day incubation study may be due to the bacteria necessary to oxidize these species. If this is true, one factor which may significantly affect the rate at which oxidation reactions occur in tailwater systems may be the rate at which the stream aquires the bacteria needed to oxidize certain chemical species. Documentation of this would require extensive field and laboratory work.

APPENDIX B: TABULAR WATER QUALITY DATA FOR INPOOL AND TAILWATER STATIONS

Table B1

Lake Greeson Reservoir Profiles

In Situ Measurements

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
		March 25, 1987, 1430 hr		
0	12.9	9.1	6.3	19
1	12.9	8.8	6.3	19
2	12.8	8.8	6.3	19
3	12.8	8.8	6.3	19
4	12.8	8.7	6.3	19
5	12.8	8.8	6.3	19
6	12.8	8.5	6.3	19
7	12.7	8.6	6.3	20
8	12.7	8.5	6.3	20
9	12.5	8.2	6.3	20
10	12.3	8.2	6.3	20
11	11.8	8.2	6.3	20
12	11.7	7.9	6.2	20
13	11.4	7.9	6.2	20
14	11.0	8.0	6.3	20
15	10.5	7.8	6.2	19
16	10.2	7.9	6.2	19
17	10.0	7.9	6.2	19
18	9.8	7.9	6.2	20
19	9.7	8.0	6.1	20
20	9.6	8.1	6.1	20
21	9.5	8.1	6.1	20
22	9.4	8.0	6.1	20
23	9.3	7.7	6.1	20
24	9.3	7.7	6.2	20
25	9.3	7.7	6.2	20
26	9.2	7.7	6.2	20
27	9.2	7.7	6.2	20
28	9.1	7.8	6.2	20
29	9.0	7.8	6.2	18
30	8.9	7.7	6.2	18
31	8.7	7.8	6.2	19
32	8.6	7.0	6.2	19
33	8.3	7.2	6.2	20
34	8.2	7.1	6.2	20
35	8.1	6.8	6.1	20
36	8.1	6.7	6.1	20
37	8.1	6.7	6.1	20
38	8.0	6.7	6.1	20

(Continued)

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B3

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
39	8.0	6.6	6.1	20
40	8.0	6.5	6.1	20
41	8.0	6.5	6.1	20
42	8.0	6.4	6.1	20
43	8.0	6.4	6.1	20

April 15, 1987, 1425 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	14.0	8.5	6.3	19
1	14.0	8.3	6.3	19
2	13.9	8.3	6.4	19
3	13.9	8.3	6.4	19
4	13.8	8.3	6.4	19
5	13.7	8.2	6.4	19
6	13.7	8.2	6.4	19
7	13.7	8.2	6.4	19
8	13.7	8.2	6.4	19
9	13.6	8.2	6.4	19
10	13.6	8.2	6.4	19
11	13.3	8.2	6.4	19
12	12.7	7.7	6.4	18
13	12.4	7.7	6.4	18
14	12.3	7.8	6.3	18
15	12.1	7.8	6.3	18
16	12.0	7.6	6.3	18
17	11.8	7.6	6.3	19
18	11.1	6.9	6.2	19
19	10.5	6.9	6.2	19
20	10.2	6.9	6.2	19
21	10.1	7.0	6.2	19
22	9.9	7.0	6.2	19
23	9.7	7.0	6.2	20
24	9.5	7.1	6.2	20
25	9.4	7.1	6.2	20
26	9.3	7.1	6.3	20
27	9.2	7.2	6.3	20
28	9.1	7.2	6.3	20
29	8.9	7.2	6.3	20
30	8.8	7.2	6.3	20
31	8.7	6.9	6.3	20
32	8.5	6.9	6.3	20
33	8.5	6.9	6.3	20
34	8.4	6.6	6.3	20
35	8.2	6.4	6.3	20

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
36	8.2	6.0	6.3	20
37	8.2	5.7	6.3	20
38	8.1	5.1	6.3	20
39	8.1	5.0	6.3	20
40	8.1	5.0	6.3	20
41	8.1	5.0	6.3	20
42	8.1	4.9	6.3	22
43	8.1	4.4	6.9	23

May 11, 1987, 1405 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	26.5	7.5	7.9	23
1	25.3	6.6	7.9	23
2	24.8	6.7	7.6	23
3	24.2	6.6	7.6	22
4	22.6	6.4	7.2	22
5	19.0	6.9	7.0	21
6	15.9	6.4	6.6	21
7	14.4	6.7	6.6	20
8	13.7	6.8	6.4	19
9	13.3	6.9	6.4	19
10	12.9	6.9	6.4	19
11	12.7	7.0	6.4	20
12	12.5	7.0	6.4	20
13	12.4	6.9	6.3	20
14	12.1	6.9	6.3	20
15	12.0	6.9	6.2	20
16	11.8	6.8	6.2	20
17	11.5	6.8	6.1	20
18	11.2	6.7	6.1	20
19	10.8	6.7	6.0	20
20	10.5	6.6	6.0	21
21	10.2	6.6	5.9	21
22	10.0	6.7	5.9	21
23	9.8	6.8	5.8	20
24	9.7	6.8	5.9	20
25	9.6	6.9	5.8	20
26	9.4	6.9	5.8	20
27	9.3	7.0	5.7	20
28	9.2	6.9	5.7	20
29	9.1	6.9	5.7	20
30	9.0	6.8	5.7	20
31	8.9	6.6	5.7	20
32	8.8	6.4	5.7	20

(Continued)

(Sheet 3 of 18)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
33	8.6	6.1	5.7	20
34	8.6	5.9	5.6	20
35	8.5	5.7	5.6	20
36	8.4	5.5	5.6	20
37	8.4	5.2	5.5	22
38	8.4	5.0	5.5	22
39	8.4	4.8	5.5	22
40	8.4	4.5	5.5	22
41	8.3	4.2	5.5	22
42	8.3	3.9	5.5	23
43	8.4	2.1	5.3	23

June 8, 1987 1408 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	27.6	7.9	7.2	22
1	27.3	7.9	7.2	22
2	27.0	8.0	7.3	22
3	26.8	8.0	7.3	22
4	26.6	8.0	7.3	22
5	22.8	9.3	7.3	23
6	18.1	8.9	6.2	21
7	16.9	7.4	5.7	19
8	14.3	6.9	5.6	19
9	13.5	6.9	5.5	18
10	13.1	6.9	5.6	18
11	12.7	7.1	5.5	18
12	12.5	7.2	5.5	18
13	12.1	7.3	5.5	18
14	11.9	7.5	5.5	19
15	11.8	7.3	5.5	19
16	11.6	7.1	5.5	19
17	11.3	7.1	5.4	19
18	11.2	7.1	5.5	19
19	10.8	7.1	5.5	19
20	10.6	7.1	5.4	19
21	10.3	7.1	5.4	19
22	10.0	7.3	5.4	18
23	9.8	7.4	5.4	18
24	9.7	7.4	5.4	18
25	9.6	7.4	5.4	18
26	9.4	7.5	5.4	18
27	9.3	7.5	5.4	18
28	9.2	7.6	5.4	18
29	9.0	7.5	5.4	18

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
30	8.9	7.3	5.3	19
31	8.8	7.1	5.3	19
32	8.7	6.8	5.3	19
33	8.6	6.7	5.3	19
34	8.5	6.1	5.3	19
35	8.4	5.7	5.2	19
36	8.4	5.1	5.2	19
37	8.4	4.8	5.2	20
38	8.3	4.5	5.2	20
39	8.3	4.1	5.2	20
40	8.3	3.5	5.2	20
41	8.2	2.7	5.2	22
42	8.3	1.1	5.2	23
43	8.3	0.9	5.2	26

July 7, 1987, 1540 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	28.8	7.9	6.8	22
1	28.4	7.4	6.8	21
2	27.7	8.0	6.8	22
3	27.6	7.8	6.9	22
4	27.4	7.8	6.8	22
5	26.0	7.7	6.5	21
6	22.2	7.8	6.2	20
7	18.2	5.9	5.8	19
8	15.7	5.1	5.7	18
9	14.3	5.5	5.6	18
10	13.5	5.8	5.6	18
11	13.0	6.1	5.6	17
12	13.4	6.4	5.6	17
13	12.4	6.5	5.5	17
14	12.2	6.6	5.5	17
15	12.0	6.7	5.5	17
16	11.8	6.6	5.5	17
17	11.7	6.6	5.4	17
18	11.4	6.6	5.4	17
19	11.2	6.6	5.4	18
20	10.9	6.4	5.4	18
21	10.6	6.8	5.4	18
22	10.4	6.8	5.4	18
23	10.2	7.0	5.4	18
24	9.9	7.2	5.4	18
25	9.8	7.2	5.4	18
26	9.6	7.1	5.3	17

(Continued)

(Sheet 5 of 18)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
27	9.5	6.9	5.3	17
28	9.3	7.0	5.3	17
29	9.2	7.0	5.3	17
30	9.0	6.8	5.3	17
31	8.9	6.6	5.3	17
32	9.0	6.2	5.2	17
33	8.8	5.6	5.2	17
34	8.9	5.3	5.2	19
35	8.8	4.9	5.2	19
36	8.7	4.5	5.2	19
37	8.6	4.1	5.2	19
38	8.6	3.4	5.2	20
39	8.6	2.5	5.2	22
40	8.6	2.0	5.2	22
41	8.6	1.4	5.2	23
42	8.6	1.3	5.2	27
43	8.6	1.2	5.3	32

July 28, 1987, 1045 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	30.4	--	6.9	24
1	30.4	--	6.7	24
2	30.3	--	6.8	24
3	30.2	--	6.8	24
4	29.9	--	7.1	24
5	29.0	--	6.9	24
6	27.0	--	6.6	24
7	21.2	--	6.0	22
8	18.3	--	5.6	22
9	15.5	--	5.5	21
10	14.3	--	5.5	20
11	13.5	--	5.4	19
12	13.0	--	5.4	19
13	12.6	--	5.4	18
14	12.3	--	5.4	18
15	12.0	--	5.4	18
16	11.8	--	5.4	19
17	11.5	--	5.3	19
18	11.4	--	5.3	19
19	11.1	--	5.3	19
20	10.7	--	5.3	19
21	10.5	--	5.2	19
22	10.2	--	5.2	19
23	9.9	--	5.2	19

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
24	9.8	--	5.3	18
25	9.7	--	5.3	20
26	9.5	--	5.3	20
27	9.3	--	5.3	20
28	9.2	--	5.3	20
29	9.0	--	5.3	20
30	9.0	--	5.3	20
31	8.8	--	5.3	18
32	8.7	--	5.3	20
33	8.6	--	5.4	20
34	8.6	--	5.4	20
35	8.5	--	5.4	22
36	8.5	--	5.4	22
37	8.4	--	5.4	23
38	8.4	--	5.4	23
39	8.4	--	5.5	24
40	8.4	--	5.5	26
41	8.4	--	5.6	30
42	8.4	--	5.6	33

August 6, 1987, 1605 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	32.3	--	7.3	27
1	31.6	--	7.3	27
2	31.4	--	7.5	27
3	31.4	--	7.5	27
4	31.3	--	7.4	27
5	30.3	--	7.3	26
6	26.4	--	6.6	25
7	23.6	--	6.4	26
8	20.1	--	5.8	26
9	17.2	--	5.6	26
10	14.7	--	5.6	25
11	13.5	--	5.5	23
12	12.9	--	5.6	22
13	12.6	--	5.4	21
14	12.5	--	5.5	21
15	12.1	--	5.4	21
16	11.9	--	5.5	21
17	11.7	--	5.4	21
18	11.5	--	5.5	21
19	11.3	--	5.4	22
20	10.9	--	5.5	22
21	10.6	--	5.4	22

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
22	10.4	--	5.5	22
23	10.2	--	5.4	22
24	10.0	--	5.5	22
25	9.8	--	5.4	22
26	9.6	--	5.4	21
27	9.4	--	5.3	21
28	9.2	--	5.4	21
29	9.0	--	5.3	21
30	9.0	--	5.4	21
31	8.9	--	5.3	21
32	8.8	--	5.3	21
33	8.7	--	5.2	21
34	8.7	--	5.3	21
35	8.6	--	5.2	23
36	8.6	--	5.3	23
37	8.6	--	5.2	24
38	8.6	--	5.3	26
39	8.5	--	5.3	27
40	8.5	--	5.4	30
41	8.5	--	5.4	36
42	8.5	--	5.6	37
43	8.5	--	6.5	45

August 15, 1987, 0935 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	30.4	7.4	--	--
1	30.5	7.7	--	--
2	30.5	7.8	--	--
3	30.5	7.7	--	--
4	30.5	7.2	--	--
5	30.1	7.2	--	--
6	27.8	6.7	--	--
7	23.8	6.5	--	--
8	19.5	3.0	--	--
9	15.4	2.2	--	--
10	14.1	2.6	--	--
11	13.5	2.9	--	--
12	12.9	3.1	--	--
14	12.3	3.2	--	--
16	11.7	2.9	--	--
18	11.1	2.7	--	--
20	10.6	2.6	--	--
22	10.0	2.3	--	--
24	9.5	2.0	--	--

(Continued)

(Sheet 8 of 18)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
26	9.1	1.7*p1715X--		--
28	8.8	1.6	--	--
30	8.6	1.1	--	--
32	8.5	0.2	--	--
34	8.4	0.0	--	--
36	8.4	0.0	--	--
38	8.5	0.0	--	--

10-Day BOD Lake Profile, August 25, 1987, 1040 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	29.8	--	8.0	28
1	29.7	--	8.1	28
2	29.7	--	8.1	28
3	29.6	--	8.1	28
4	29.6	--	8.1	28
5	29.6	--	8.1	28
6	29.2	--	7.7	25
7	24.0	--	6.7	24
8	19.3	--	5.8	22
9	15.9	--	5.6	21
10	14.3	--	5.5	20
11	13.3	--	5.5	19
12	12.9	--	5.4	19
13	12.5	--	5.4	18
14	12.3	--	5.4	18
15	12.0	--	5.4	19
16	11.9	--	5.5	19
17	11.6	--	5.4	19
18	11.4	--	5.4	19
19	11.1	--	5.4	19
20	10.9	--	5.4	19
21	10.6	--	5.4	19
22	10.4	--	5.4	19
23	10.1	--	5.3	19
24	10.0	--	5.4	19
25	9.7	--	5.3	20
26	9.6	--	5.3	20
27	9.4	--	5.3	20
28	9.3	--	5.3	20
29	9.2	--	5.3	20
30	9.1	--	5.3	20
31	9.0	--	5.3	18
32	8.9	--	5.3	20
33	8.8	--	5.3	20

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
34	8.8	--	5.3	20
35	8.7	--	5.2	21
36	8.7	--	5.3	24
37	8.6	--	5.3	27
38	8.6	--	5.3	36
39	8.6	--	5.4	45
40	8.6	--	5.6	52

September 3, 1987, 1500 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	29.8	7.8	8.2	25
1	29.6	7.9	8.2	25
2	28.6	8.0	8.3	24
3	28.0	8.2	8.3	24
4	27.8	8.2	8.4	24
5	27.5	8.0	8.3	24
6	27.3	7.5	8.2	23
7	24.1	3.6	6.9	22
8	21.4	1.7	6.2	21
9	18.1	1.2	6.0	22
10	15.9	1.6	5.8	21
11	14.3	2.1	5.8	19
12	13.7	2.4	5.7	18
13	12.9	3.1	5.7	17
14	12.6	3.3	5.7	17
15	12.3	3.4	5.6	16
16	12.1	3.5	5.6	16
17	11.9	3.5	5.6	16
18	11.7	3.5	5.6	16
19	11.5	3.6	5.6	16
20	11.2	3.7	5.6	16
21	10.8	3.7	5.5	16
22	10.6	3.8	5.5	16
23	10.3	3.7	5.5	17
24	10.1	3.6	5.5	17
25	10.0	3.4	5.5	17
26	9.8	3.2	5.5	17
27	9.6	3.0	5.4	17
28	9.4	3.0	5.4	17
29	9.3	2.9	5.4	17
30	9.3	3.0	5.4	17
31	9.1	3.4	5.5	17
32	9.0	3.6	5.4	16
33	8.9	3.1	5.4	16

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
34	8.9	2.1	5.4	17
35	8.8	1.4	5.4	17
36	8.8	0.5	5.4	19
37	8.7	0.3	5.4	21
38	8.7	0.3	5.5	27
39	8.7	0.3	5.6	33
40	8.7	0.3	5.7	42
41	8.7	0.3	5.8	52
42	8.7	0.3	6.0	60

September 12, 1987, 0700 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	25.6	8.8	8.0	29
1	25.6	8.6	8.1	28
2	25.6	8.5	8.0	30
3	25.6	8.3	8.1	29
4	25.6	8.3	8.0	29
5	25.6	8.3	8.1	29
6	25.3	6.2	7.5	27
7	24.8	5.0	6.8	28
8	21.1	1.6	6.5	27
9	18.0	0.9	5.7	28
10	15.6	1.2	5.6	26
11	14.1	2.0	5.5	24
12	12.6	2.5	5.5	23
13	12.2	3.0	5.5	22
14	12.0	3.2	5.5	22
15	11.8	3.4	5.5	23
16	11.5	3.5	5.5	23
17	11.3	3.7	5.5	23
18	11.1	3.8	5.5	23
19	10.9	3.8	5.5	22
20	10.6	3.9	5.5	22
21	10.4	3.9	5.5	23
22	10.2	3.8	5.5	23
23	9.9	3.7	5.5	24
24	9.7	3.8	5.5	24
25	9.5	3.5	5.5	24
26	9.3	3.3	5.4	24
27	9.2	3.0	5.5	24
28	9.0	2.8	5.4	24
29	8.9	2.8	5.5	24
30	8.7	3.5	5.5	23
31	8.7	3.6	5.5	23

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
32	8.6	3.5	5.5	23
33	8.5	2.5	5.5	24
34	8.4	1.5	5.4	26
35	8.4	0.8	5.5	26
36	8.4	0.6	5.5	30
37	8.3	0.5	5.6	36
38	8.3	0.5	5.7	49
39	8.3	0.5	5.8	58
40	8.3	0.5	5.9	77
41	8.4	0.5	6.2	85
42	8.4	0.5	6.2	134

September 12, 1987, 1550 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	26.9	9.2	--	--
1	26.9	8.9	--	--
2	26.9	8.6	--	--
3	26.9	8.4	--	--
4	26.9	8.4	--	--
5	26.7	8.1	--	--
6	26.0	5.7	--	--
7	25.0	3.6	--	--
8	20.9	1.1	--	--
9	17.8	0.9	--	--
10	15.8	1.4	--	--
11	14.0	2.1	--	--
12	13.0	2.6	--	--
13	12.5	3.0	--	--
14	12.1	3.2	--	--
15	11.9	3.3	--	--
16	11.6	3.5	--	--
17	11.4	3.6	--	--
18	11.1	3.7	--	--
19	10.9	3.7	--	--
20	10.7	3.8	--	--
21	10.2	3.8	--	--
22	10.1	3.6	--	--
23	9.9	3.5	--	--
24	9.5	3.8	--	--
25	9.3	3.6	--	--
26	9.1	2.7	--	--
27	9.0	2.6	--	--
28	9.0	2.8	--	--
29	8.9	3.6	--	--

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
30	8.7	3.6	--	--
31	8.6	3.3	--	--
32	8.5	2.3	--	--
33	8.3	0.7	--	--
34	8.3	0.6	--	--
35	8.3	0.6	--	--
36	8.3	0.6	--	--
37	8.3	0.6	--	--
38	8.3	0.6	--	--
39	8.3	0.6	--	--
40	8.3	0.6	--	--

September 13, 1987, 1430 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	27.4	8.2	--	--
1	27.0	8.3	--	--
2	26.9	8.3	--	--
3	26.8	8.2	--	--
4	26.7	8.1	--	--
5	26.7	8.0	--	--
6	26.6	7.9	--	--
7	25.3	3.4	--	--
8	21.1	1.1	--	--
9	17.5	0.9	--	--
10	15.4	1.4	--	--
11	14.1	2.0	--	--
12	13.1	2.5	--	--
13	12.7	2.5	--	--
14	12.3	2.8	--	--
15	12.0	3.2	--	--
16	11.9	3.3	--	--
17	11.5	3.4	--	--
18	11.3	3.5	--	--
19	11.0	3.7	--	--
20	10.8	3.7	--	--
21	10.5	3.7	--	--
22	10.2	3.6	--	--
23	10.0	3.5	--	--
24	9.9	3.3	--	--
25	9.6	3.3	--	--
26	9.3	3.0	--	--
27	9.2	2.9	--	--
28	9.1	2.7	--	--
29	9.0	3.5	--	--

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
30	8.9	3.4	- -	- -
31	8.8	3.4	- -	- -
32	8.6	2.9	- -	- -
33	8.5	1.1	- -	- -
34	8.5	0.8	- -	- -
35	8.5	0.7	- -	- -
36	8.5	0.7	- -	- -
37	8.5	0.7	- -	- -
38	8.4	0.7	- -	- -
39	8.4	0.6	- -	- -
40	8.4	0.6	- -	- -
41	8.4	0.6	- -	- -

September 14, 1987, 0540 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	25.3	7.5	8.0	26
1	25.3	7.5	8.1	28
2	25.3	7.5	8.1	29
3	25.2	7.5	8.1	28
4	25.2	7.4	8.1	29
5	25.2	7.4	8.2	29
6	25.2	7.4	8.2	29
7	23.5	2.1	6.4	28
8	21.2	0.8	5.6	28
9	16.8	0.7	5.4	27
10	14.8	1.3	5.4	26
11	13.3	1.7	5.4	23
12	12.5	2.3	5.4	24
13	12.1	2.3	5.3	22
14	11.9	2.6	5.4	21
15	11.6	2.9	5.3	21
16	11.4	3.0	5.4	21
17	11.2	3.1	5.4	22
18	10.8	3.3	5.4	20
19	10.6	3.3	5.4	21
20	10.4	3.4	5.3	21
21	10.0	3.3	5.4	21
22	9.8	3.2	5.4	22
23	9.7	3.2	5.4	22
24	9.5	3.0	5.4	22
25	9.2	2.9	5.4	22
26	9.1	2.6	5.4	21
27	8.9	2.5	5.4	23
28	8.8	2.4	5.4	21

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
29	8.7	2.5	5.4	21
30	8.7	2.9	5.4	21
31	8.5	2.9	5.4	22
32	8.5	2.8	5.4	22
33	8.3	2.2	5.4	23
34	8.3	0.7	5.4	25
35	8.2	0.6	5.4	26
36	8.2	0.6	5.5	30
37	8.2	0.5	5.6	43
38	8.2	0.5	5.7	49
39	8.2	0.5	5.8	59
40	8.2	0.5	6.0	67
41	8.2	0.5	6.0	88

October 12, 1987, 1420 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	21.1	7.5	--	--
1	21.0	7.2	--	--
2	20.9	6.9	--	--
3	20.5	6.8	--	--
4	20.4	6.7	--	--
5	20.3	6.7	--	--
6	20.3	6.6	--	--
7	20.2	6.6	--	--
8	20.1	6.6	--	--
9	20.1	6.6	--	--
10	20.0	5.9	--	--
11	15.0	1.6	--	--
12	14.0	1.9	--	--
13	13.0	2.1	--	--
14	12.5	2.3	--	--
15	12.0	2.4	--	--
16	11.9	2.6	--	--
17	11.5	2.8	--	--
18	11.1	2.9	--	--
19	11.0	3.0	--	--
20	10.6	3.0	--	--
21	10.2	3.0	--	--
22	10.0	2.6	--	--
23	9.9	2.4	--	--
24	9.7	2.1	--	--
25	9.3	2.1	--	--
26	9.1	2.1	--	--
27	9.0	2.4	--	--

(Continued)

(Sheet 15 of 18)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
28	8.9	3.0	- -	- -
29	8.9	3.0	- -	- -
30	8.8	3.0	- -	- -
31	8.5	2.6	- -	- -
32	8.5	1.3	- -	- -
33	8.3	1.1	- -	- -
34	8.3	1.0	- -	- -
35	8.2	1.0	- -	- -
36	8.2	1.0	- -	- -
37	8.3	1.0	- -	- -
38	8.3	1.1	- -	- -
39	8.2	1.1	- -	- -
40	8.3	1.1	- -	- -
41	8.3	1.0	- -	- -

October 14, 1987, 0713 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	19.8	6.6	- -	- -
1	19.9	6.5	- -	- -
2	19.9	6.5	- -	- -
3	19.9	6.9	- -	- -
4	19.9	6.4	- -	- -
5	19.9	6.4	- -	- -
6	19.9	6.3	- -	- -
7	19.9	6.3	- -	- -
8	19.9	6.3	- -	- -
9	19.9	6.2	- -	- -
10	19.9	6.2	- -	- -
11	16.3	1.1	- -	- -
12	14.5	1.2	- -	- -
13	13.2	1.5	- -	- -
14	12.7	1.7	- -	- -
15	12.2	1.8	- -	- -
16	12.0	2.0	- -	- -
17	11.6	2.3	- -	- -
18	11.2	2.4	- -	- -
19	11.0	2.6	- -	- -
20	10.9	2.5	- -	- -
21	10.5	2.5	- -	- -
22	10.2	2.3	- -	- -
23	10.0	2.0	- -	- -
24	9.8	1.8	- -	- -
25	9.5	1.6	- -	- -
26	9.3	1.5	- -	- -

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
27	9.0	1.7	--	--
28	9.0	2.5	--	--
29	8.9	2.7	--	--
30	8.8	2.6	--	--
31	8.8	2.7	--	--
32	8.7	1.1	--	--
33	8.5	0.7	--	--
34	8.5	0.7	--	--
35	8.5	0.7	--	--
36	8.4	0.7	--	--
37	8.4	0.7	--	--
38	8.4	0.9	--	--
39	8.4	0.9	--	--
40	8.5	0.8	--	--

November 3, 1987, 0950 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	18.5	8.2	6.6	44
1	18.5	8.0	6.7	44
2	18.4	8.0	6.7	44
3	18.4	7.9	6.7	45
4	18.3	7.8	6.7	46
5	18.3	7.9	6.7	46
6	18.3	7.8	6.7	46
7	18.3	7.9	6.7	46
8	18.3	7.5	6.7	46
9	18.0	7.2	6.7	46
10	18.0	7.0	6.6	46
11	17.9	6.2	6.5	46
12	17.2	2.8	6.3	46
13	16.0	0.3	6.1	48
14	14.9	0.1	6.1	48
15	13.7	0.3	6.1	47
16	13.3	0.6	6.1	46
17	12.7	0.8	6.1	46
18	12.2	1.0	6.1	46
19	11.9	1.4	6.1	46
20	11.6	1.6	6.1	46
21	11.1	1.9	6.2	46
22	10.9	1.8	6.2	47
23	10.6	1.7	6.2	47
24	10.4	1.5	6.2	47
25	10.1	1.1	6.1	48
26	10.0	1.0	6.1	47

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
27	9.7	1.0	6.1	48
28	9.6	1.3	6.1	47
29	9.4	1.8	6.2	47
30	9.3	2.0	6.2	47
31	9.1	2.0	6.2	47
32	9.1	1.6	6.2	47
33	9.0	0.2	6.2	47
34	9.0	0.0	6.3	51
35	8.8	0.0	6.5	61
36	8.8	0.0	6.6	74
37	8.8	0.0	6.7	79
38	8.8	0.0	6.8	88
39	8.7	0.0	7.0	99
40	8.8	0.0	7.1	109
41	8.8	0.0	7.1	115

Table B2

Lake Greeson 6-hr Generation Pre-Generation Lake Sampling*

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO² mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ	TP mg/ℓ
			July 28, 1987, 1045 hr				
0	1.6	13	1	4.3	0.4	2	0.008
2	1.4	13	4	4.2	0.4	2	0.010
4	1.4	8	2	3.7	0.4	2	0.010
6	1.6	8	4	4.4	0.4	2	0.009
8	1.0	8	9	3.8	0.7	2	0.012
10	1.7	8	10	3.5	0.7	2	0.009
12	1.2	8	10	3.8	0.8	2	0.013
14	1.1	8	9	3.0	0.6	1	0.008
16	0.73	8	10	3.2	0.6	2	0.008
18	1.2	8	8	3.6	0.6	1	0.009
20	1.1	8	10	3.1	0.7	0	0.010
22	1.3	8	9	3.5	0.7	1	0.016
24	1.5	8	9	3.1	0.8	1	0.013
26	1.8	9	11	3.4	0.7	3	0.017
28	1.7	8	11	4.2	0.9	2	0.009
30	1.2	8	12	3.6	1.0	2	0.008
32	0.92	8	10	3.2	0.8	2	0.009
34	2.0	8	12	3.0	0.9	2	0.012
36	3.5	10	13	3.4	1.0	3	0.015
38	5.5	12	15	4.2	1.4	3	0.025
40	6.0	12	16	4.2	1.4	4	0.028
42	38.	15	16	5.7	1.8	13	0.035

(Continued)

* Pool elevation at 164.57 m.

(Sheet 1 of 13)

Table B2 (Continued)

Depth m	D.P. mg/ℓ	S.R.P mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH₃-N mg/ℓ	NO₃-N mg/ℓ
0	0.003	0.000	0.4	0.3	0.03	0.00
2	0.006	0.000	0.2	0.2	0.05	0.00
4	0.003	0.000	0.3	0.3	0.02	0.00
6	0.006	0.000	0.4	0.3	0.01	0.00
8	0.004	0.000	0.2	0.1	0.01	0.04
10	0.004	0.000	0.4	0.2	0.01	0.11
12	0.002	0.000	0.1	0.1	0.02	0.18
14	0.006	0.000	0.1	0.0	0.02	0.19
16	0.008	0.000	0.2	0.3	0.02	0.21
18	0.003	0.000	0.0	0.2	0.03	0.16
20	0.006	0.000	0.1	0.1	0.04	0.21
22	0.002	0.000	0.1	0.3	0.04	0.22
24	0.002	0.000	0.1	0.2	0.01	0.23
26	0.012	0.002	0.1		0.03	0.25
28	0.004	0.000	0.1	0.2	0.02	0.25
30	0.007	0.000	0.1	0.4	0.02	0.26
32	0.007	0.000	0.1	0.2	0.01	0.25
34	0.003	0.000	0.1	0.2	0.02	0.29
36	0.005	0.000	0.1	0.2	0.04	0.30
38	0.005	0.000	0.2	0.2	0.15	0.18
40	0.008	0.000	0.3	0.5	0.12	0.23
42	0.007	0.002	0.6		0.33	0.03

(Continued)

Depth m	S= mg/ℓ	SO$_4$= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
0	0.0	3.1	1.8	0.00	0.00	0.01	0.00
2	0.0	2.8	1.6	0.00	0.00	0.01	0.00
4	0.0	2.8	1.7	0.00	0.00	0.02	0.00
6	0.0	2.6	1.5	0.00	0.00	0.01	0.00
8	0.0	2.9	1.4	0.01	0.00	0.02	0.01
10	0.0	2.2	1.5	0.03	0.02	0.02	0.01
12	0.0	2.3	1.4	0.11	0.03	0.04	0.02
14	0.0	2.6	1.4	0.08	0.05	0.02	0.01
16	0.0	2.5	1.5	0.06	0.01	0.03	0.02
18	0.0	2.3	1.5	0.06	0.03	0.04	0.01
20	0.0	2.3	1.5	0.08	0.04	0.07	0.05
22	0.0	2.4	1.5	0.10	0.06	0.08	0.06
24	0.0	2.6	1.6	0.04	0.05	0.11	0.08
26	0.0	2.6	1.6	0.10	0.08	0.12	0.10
28	0.0	2.5	1.6	0.12	0.10	0.12	0.12
30	0.0	2.5	1.6	0.14	0.11	0.14	0.13
32	0.0	2.4	1.6	0.09	0.09	0.08	0.08
34	0.0	2.5	1.5	0.19	0.13	0.15	0.14
36	0.0	2.2	1.5	0.52	0.15	0.41	0.38
38	0.0	2.0	1.6	1.6	0.20	0.97	0.90
40	0.0	2.4	1.7	1.4	0.27	0.83	0.79
42	0.0	2.3	1.7	4.0	0.47	1.4	1.3

(Continued)

Table B2 (Continued)

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ	TP mg/ℓ
			July 28, 1987, 1700 hr				
0	1.4	8	1	4.4	0.8	1	0.003
2	1.6	9	3	3.8	0.7	1	0.006
4	1.2	9	2	3.9	0.7	2	0.007
6	1.1	8	3	3.6	0.7	4	0.006
8	0.85	9	9	4.6	0.9	2	0.009
10	1.3	8	10	6.1	0.8	2	
12	0.65	8	8	4.7	0.8	2	0.007
14	0.72	8	8	4.7	0.8	2	0.006
16	1.0	8	8	5.8	0.8	1	0.005
18	2.4	8	8	5.1	0.9	3	0.002
20	1.0	8	9	3.5	0.9	1	0.009
22	0.89	8	8	3.4	1.1	0	0.003
24	1.3	8	6	5.4	0.8	1	0.008
26	1.4	8	8	3.2	0.6	1	0.005
28	0.79	8	8	3.9	0.7	2	0.001
30	0.80	8	10	4.5	0.8	2	0.008
32	0.89	9	8	3.9	0.7	1	0.002
34	1.7	9	10	4.1	0.8	1	0.002
36	1.6	9	11	3.3	0.8	1	0.010
38	3.0	10	11	3.7	0.8	4	0.036
40	15.0	12	11	5.1	1.2	3	0.059
42	22.0	14	17	4.7	1.2	6	0.025

(Continued)

Table B2 (Continued)

Depth m	D.P. mg/ℓ	S.R.P mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ
0	0.008	0.000	0.7	0.4	0.03	0.00
2	0.003	0.000	0.4	0.2	0.01	0.00
4	0.004	0.000	0.2	0.4	0.01	0.00
6	0.005	0.000	0.5	0.2	0.00	0.00
8	0.004	0.000	0.3	0.2	0.01	0.03
10	0.004	0.000	0.3	0.1	0.01	0.13
12	0.006	0.000	0.2	0.3	0.01	0.18
14	0.010	0.000	0.1	0.0	0.01	0.20
16	0.012	0.000	0.5	0.1	0.01	0.21
18	0.007	0.000	0.2	0.4	0.01	0.20
20	0.007	0.001	0.5	0.2	0.01	0.20
22	0.013	0.000	0.2	0.2	0.01	0.20
24	0.019	0.000	0.2	0.2	0.01	0.22
26	0.006	0.000	0.2	0.2	0.01	0.22
28	0.004	0.000	0.2	0.1	0.01	0.21
30	0.005	0.000	0.4	0.1	0.01	0.26
32	0.012	0.000	0.2	0.2	0.00	0.22
34	0.006	0.000	0.2	0.1	0.01	0.28
36	0.005	0.000	0.1	0.1	0.02	0.32
38	0.005	0.000	0.1	0.1	0.02	0.32
40	0.013	0.002	0.2	0.3	0.07	0.34
42	0.004	0.000	0.3	0.4	0.16	0.25

(Continued)

Depth m	S= mg/ℓ	SO$_4$= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
0	0.0	2.7	2.0	0.00	0.00	0.02	0.00
2	0.0	2.5	1.5	0.00	0.00	0.02	0.00
4	0.0	2.5	1.6	0.00	0.00	0.01	0.00
6	0.0	2.5	1.5	0.02	0.00	0.02	0.00
8	0.0	2.6	1.5	0.03	0.00	0.03	0.00
10	0.0	2.5	1.5	0.05	0.00	0.02	0.00
12	0.0	2.7	1.5	0.04	0.00	0.03	0.00
14	0.0	2.6	1.5	0.04	0.02	0.03	0.00
16	0.0	2.7	1.6	0.03	0.01	0.02	0.01
18	0.0	2.7	1.6	0.04	0.01	0.04	0.02
20	0.0	2.6	1.5	0.04	0.01	0.06	0.03
22	0.0	2.5	1.5	0.06	0.02	0.08	0.05
24	0.0	2.6	1.7	0.09	0.04	0.11	0.07
26	0.0	2.8	2.2	0.11	0.04	0.10	0.08
28	0.0	1.9	2.0	0.15	0.03	0.11	0.10
30	0.0	2.7	2.2	0.19	0.06	0.15	0.12
32	0.0	2.5	2.5	0.13	0.05	0.10	0.09
34	0.0	2.5	2.4	0.19	0.05	0.14	0.12
36	0.0	2.5	2.5	0.43	0.15	0.35	0.30
38	0.0	2.3	2.5	0.71	0.25	0.60	0.59
40	0.0	2.4	2.2	1.2	0.24	0.83	0.80
42	0.0	1.7	2.5	3.8	0.90	1.4	1.4

(Continued)

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO^2 mg/ℓ	TOC mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ	TP mg/ℓ
			48-hr Generation, September 12, 1987*					
0	3.0	8	0	6.7	4.9	1.1	6	0.015
2	1.9	9	0	6.6	5.1	1.2	9	0.022
4	2.4	9	0	6.1	5.9	1.1	6	0.017
6	1.9	10	0	6.6	6.6	1.5	4	0.010
8	1.5	6	9	5.0	5.4	3.0	5	0.017
10	2.0	8	13	·.0	4.5	3.4	2	0.007
12	1.5	8	11	3.2	4.8	3.0	5	0.006
14	1.4	8	12	4.0	5.0	2.6	7	0.021
16	1.3	8	10	3.6	3.9	3.1	2	0.004
18	1.7	8	9	3.4	4.3	2.9	5	0.010
20	1.4	8	10	4.4	3.5	1.7	5	0.003
22	2.0	9	9	3.6	3.5	2.0	3	0.009
24	1.9	8	11	3.7	3.8	2.1	2	0.002
26	2.0	9	11	3.6	4.9	2.3	4	0.018
28	2.8	9	11	3.7	3.5	2.4	5	0.016
30	2.1	9	10	3.6	3.0	3.1	3	0.007
32	2.0	6	10	4.6	4.4	2.8	4	0.016
34	7.7	11	13	5.7	4.7	4.1	5	0.036
36	18.	14	15	4.9	3.9	5.0	6	0.036
38	46.	20	19	8.2	5.7	6.1	2	0.030
40	54.	23	29	7.2	6.7	6.8	3	0.076

(Continued)

* Pool elevation at 163.84 m.

Table B2 (Continued)

Depth m	D.P. mg/ℓ	S.R.P mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH₃-N mg/ℓ	NO₃-N mg/ℓ	S= mg/ℓ	SO₄= mg/ℓ
0	0.011	0.002	0.4	0.1	0.00	0.00	0.0	2.6
2	0.010	0.001	0.1	0.1	0.02	0.00	0.0	2.5
4	0.009	0.002	0.2	0.2	0.00	0.00	0.0	2.6
6	0.007	0.002	0.2	0.1	0.01	0.00	0.0	2.6
8	0.007	0.000	0.1	0.1	0.00	0.00	0.0	2.3
10	0.003	0.000	0.1	0.0	0.01	0.09	0.0	2.5
12	0.004	0.000	0.1	0.0	0.01	0.18	0.0	2.7
14	0.006	0.000	0.2	0.0	0.00	0.21	0.0	2.8
16	0.004	0.000	0.1	0.1	0.00	0.22	0.0	2.9
18	0.005	0.000	0.0	0.1	0.00	0.23	0.0	2.6
20	0.003	0.000	0.0	0.0	0.00	0.24	0.0	2.8
22	0.005	0.000	0.1	0.1	0.00	0.25	0.0	2.0
24	0.007	0.000	0.1	0.1	0.00	0.27	0.0	2.9
26	0.007	0.001	0.1	0.0	0.01	0.28	0.0	2.8
28	0.005	0.000	0.0	0.0	0.02	0.30	0.0	2.4
30	0.005	0.000	0.0	0.1	0.00	0.29	0.0	2.6
32	0.005	0.000	0.1	0.0	0.00	0.29	0.0	2.9
34	0.007	0.000	0.2	0.1	0.08	0.23	0.0	2.3
36	0.006	0.000	0.4	0.3	0.20	0.24	0.0	1.9
38	0.005	0.003	0.9	0.7	0.50	0.00	0.0	2.0
40	0.011	0.008	1.1	1.0	0.75	0.00	0.0	1.6

(Continued)

Table B2 (Continued)

Depth m	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T. Mn mg/ℓ	D.Mn mg/ℓ
0	1.5	0.08	0.05	0.02	0.02
2	1.5	0.08	0.02	0.02	0.00
4	1.5	0.10	0.03	0.02	0.00
6	1.5	0.11	0.03	0.02	0.00
8	1.5	0.11	0.03	0.02	0.00
10	1.6	0.11	0.03	0.12	0.09
12	1.4	0.11	0.02	0.09	0.07
14	1.4	0.10	0.02	0.09	0.07
16	1.6	0.12	0.04	0.11	0.09
18	1.6	0.12	0.03	0.13	0.11
20	1.6	0.10	0.04	0.14	0.12
22	1.6	0.14	0.05	0.17	0.15
24	1.5	0.16	0.07	0.19	0.16
26	1.6	0.23	0.07	0.20	0.17
28	1.6	0.28	0.09	0.24	0.20
30	1.6	0.20	0.05	0.20	0.17
32	1.6	0.22	0.05	0.21	0.19
34	1.6	0.99	0.12	0.73	0.66
36	1.8	2.2	0.44	1.07	1.01
38	1.7	5.0	2.1	1.8	1.6
40	1.8	9.0	1.9	2.2	1.8

(Continued)

Table B2 (Continued)

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO^2 mg/ℓ	TOC mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ	TP mg/ℓ
			48-hr Generation, September 14, 1987					
0	1.9	10	0	7.8	5.0	1.2	2	0.026
2	1.8	11	0	7.7	4.2	1.3	2	0.032
4	1.6	10	0	7.8	7.0	1.4	1	0.028
6	1.7	10	0	6.8	7.5	1.3	2	0.02
8	1.6	10	11	5.1	5.6	3.6	1	0.022
10	1.8	9	13	4.6	3.9	3.4	1	0.014
12	1.4	8	11	4.6	4.2	3.7	0	0.015
14	1.4	9	11	5.0	--	3.5	1	0.014
16	1.4	8	9	--	3.0	3.0		0.011
18	1.3	9	8	4.8	4.0	3.0	1	0.014
20	1.7	8	8	4.8	3.7	3.1	1	0.012
22	1.8	10	8	4.3	4.2	3.8	1	0.015
24	2.4	10	9	3.4	4.2	3.2	2	0.022
26	2.4	9	9	3.8	4.6	3.7	2	0.015
28	1.5	10	11	3.5	3.8	3.7	1	0.016
30	1.7	9	9	3.5	4.1	3.6	1	0.017
32	1.6	9	11	3.6	4.2	3.4	1	0.018
34	5.3	11	12	4.8	5.0	4.9	1	0.020
36	20.	16	15	6.8	6.3	5.2	5	0.048
38	39.	25	20	6.7	5.8	6.8	13	0.041
40	41.	34	27	7.6	7.1	7.5	17	0.054

(Continued)

Depth m	D.P. mg/ℓ	S.R.P mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	S= mg/ℓ	SO_4= mg/ℓ
0	0.009	0.003	0.3	0.2	0.01	0.02	0.0	2.6
2	0.006	0.003	0.2	0.1	0.02	0.00	0.0	2.5
4	0.009	0.005	0.2	0.1	0.00	0.00	0.0	2.5
6	0.011	0.005	0.2	0.1	0.00	0.00	0.0	2.5
8	0.005	0.000	0.2	0.1	0.01	0.04	0.0	2.6
10	0.001	0.000	0.1	0.1	0.00	0.11	0.0	2.8
12	0.000	0.000	0.1	0.0	0.00	0.17	0.0	2.8
14	0.003	0.000	0.1	0.1	0.01	0.20	0.0	2.6
16	0.004	0.000	0.1	0.2	0.01	0.22	0.0	2.6
18	0.004	0.000	0.1	0.1	0.01	0.22	0.0	2.8
20	0.002	0.000	0.1	0.1	0.01	0.24	0.0	2.7
22	0.004	0.000	0.1	0.1	0.00	0.26	0.0	2.7
24	0.001	0.000	0.2	0.0	0.00	0.27	0.0	2.6
26	0.003	0.000	0.1	0.0	0.01	0.29	0.0	2.6
28	0.002	0.000	0.1	0.0	0.00	0.30	0.0	2.7
30	0.003	0.000	0.1	0.1	0.00	0.29	0.0	2.6
32	0.002	0.000	0.2	0.0	0.01	0.31	0.0	2.5
34	0.003	0.000	0.1	0.1	0.03	0.27	0.0	2.5
36	0.008	0.000	0.4	0.7	0.26	0.06	0.0	2.3
38	0.014	0.002	0.9	0.7	0.52	0.00	0.0	1.9
40	0.016	0.005	1.2	1.0	0.77	0.00	0.0	1.8

(Continued)

Table B2 (Continued)

Depth m	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T. Mn mg/ℓ	D.Mn mg/ℓ
0	1.6	0.00	0.00	0.00	0.00
2	1.7	0.03	0.00	0.02	0.00
4	1.8	0.03	0.00	0.01	0.00
6	1.6	0.02	0.03	0.02	0.00
8	1.6	0.05	0.02	0.02	0.00
10	1.7	0.05	0.02	0.12	0.09
12	1.6	0.06	0.04	0.16	0.13
14	1.7	0.08	0.05	0.12	0.10
16	1.6	0.05	0.06	0.11	0.08
18	1.6	0.06	0.06	0.13	0.11
20	1.7	0.07	0.06	0.14	0.12
22	1.8	0.16	0.08	0.18	0.15
24	1.7	0.22	0.10	0.19	0.17
26	1.9	0.28	0.13	0.20	0.18
28	1.8	0.30	0.13	0.22	0.21
30	1.7	0.25	0.11	0.21	0.19
32	1.8	0.34	0.14	0.26	0.25
34	1.9	0.79	0.28	0.58	0.57
36	1.8	2.6	0.39	1.17	1.14
38	2.0	6.6	3.4	2.0	1.8
40	2.3	11.	7.2	2.4	2.2

(Continued)

Depth m	pH	S.C. uS	Turbidity NTU	Alkalinity mg/ℓ	CO^2 mg/ℓ	TOC mg/ℓ	TP mg/ℓ	SRP mg/ℓ

6-hr Generation, October 14, 1987, 0715 hr*

Depth m	pH	S.C. uS	Turbidity NTU	Alkalinity mg/ℓ	CO^2 mg/ℓ	TOC mg/ℓ	TP mg/ℓ	SRP mg/ℓ
0	6.5	36	2.1	10	4	5.0	0.013	0.000
5	6.5	37	2.3	11	3	5.2	0.013	0.000
10	6.4	35	2.1	10	3	5.2	0.010	0.000
12	5.9	37	2.2	9	9	3.7	0.008	0.000
14	6.0	34	1.8	8	7	3.6	0.010	0.003
16	5.9	33	2.2	9	9	4.1	0.013	0.000
18	5.9	34	1.8	9	5	3.8	0.009	0.000
20	5.7	34	2.1	10	6	3.7	0.006	0.000
25	6.0	35	2.8	9	8	3.5	0.011	0.000
30	6.0	36	2.4	10	9	4.0	0.027	0.001
35	6.3	50	38.	22	13	5.7	0.033	0.000
40	6.6	60	--	42	30	9.2	0.068	0.043

Depth m	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	S= mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
0	0.2	0.02	0.01	0.00	0.03	0.05	0.06	0.04
5	0.2	0.02	0.02	0.00	0.06	0.05	0.05	0.03
10	0.2	0.02	0.02	0.00	0.06	0.06	0.06	0.02
12	0.1	0.04	0.13	0.00	0.09	0.06	0.22	0.26
14	0.1	0.02	0.17	0.00	0.06	0.06	0.24	0.21
16	0.2	0.01	0.23	0.00	0.07	0.10	0.28	0.26
18	0.1	0.02	0.22	0.00	0.11	0.07	0.24	0.22
20	0.1	0.02	0.26	0.00	0.14	0.10	0.26	0.24
25	0.1	0.02	0.30	0.00	0.29	0.15	0.29	0.27
30	0.2	0.01	0.31	0.00	0.23	0.13	0.26	0.24
35	0.9	0.48	0.01	0.00	3.6	1.5	1.5	1.5
40	1.9	1.2	0.02	0.00	15.6	15.4	1.8	0.7

* Pool elevation at 163.23 m.

Table B3

Lake Greeson Steady-State Station B

River Sampling, July 28, 1987

Time	Temperature °C	DO mg/ℓ	pH	SC μsec	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ
1030	14.2	6.5	6.3	43	1.3	8	11
1100	14.1	6.8	6.4	30	1.0	8	8
1130	14.0	6.6	6.4	29	1.6	8	8
1200	14.0	7.1	6.3	30	1.2	8	5
1230	14.0	6.5	6.2	30	1.9	8	8
1300	14.0	6.2	6.2	33	1.2	7	10
1330	14.1	6.2	6.2	30	1.5	8	8
1400	14.0	6.1	6.2	28	1.1	8	9
1430	14.0	6.0	6.2	24	1.6	8	8
1500	13.9	5.0	6.2	24	0.90	8	8
1530	13.5	5.0	6.2	26	1.3	8	9
1600	13.0	4.0	6.4	24	1.3	8	8
1630	13.0	3.4	6.3	24	1.1	8	8
1700	13.0	2.8	6.2	24	1.0	8	9
1730	12.9	3.3	6.4	24	1.1	8	8
1800	13.0	4.0	6.3	24	1.6	8	11
1830	13.0	4.6	6.4	25	1.7	7	9
1900	13.5	4.8	6.4	24	1.5	8	8

Time	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ	TP mg/ℓ	DP mg/ℓ	SRP mg/ℓ	T.TKN mg/ℓ
1030	4.6	0.9	1	0.007	0.014	0.010	0.8
1100	4.2	0.7	2	0.008	0.008	0.000	0.1
1130	4.5	0.7	2	0.011	0.012	0.000	0.3
1200	3.6	0.6	1	0.008	0.010	0.000	0.1
1230	4.0	0.7	1	0.006	0.010	0.000	0.2
1300	3.3	0.7	1	0.008	0.008	0.000	0.1
1330	3.8	0.8	1	0.012	0.006	0.000	0.1
1400	3.7	0.7	1	0.022	0.025	0.009	0.2
1430	3.2	0.6	1	0.008	0.005	0.000	0.1
1500	4.4	0.4	2	0.016	0.007	0.000	0.1
1530	3.6	0.5	1	0.008	0.002	0.000	0.2
1600	4.5	0.5	1	0.007	0.007	0.000	0.1
1630	4.9	0.4	1	0.004	0.008	0.000	0.2
1700	4.8	0.5	1	0.007	0.005	0.000	0.1
1730	3.7	0.6	1	0.015	0.003	0.000	0.1
1800	3.8	0.7	1	0.012	0.008	0.000	0.1
1830	4.3	0.6	2	0.018	0.015	0.000	0.1
1900	3.8	0.7	1	0.006	0.006	0.000	0.1

(Continued)

Table B3 (Concluded)

Time	D.TKN mg/ℓ	NH₃-N mg/ℓ	NO₃-N mg/ℓ	S- mg/ℓ	SO₄= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
1030	0.6	0.01	0.21	0.00	3.1	1.5	0.13	0.11	0.05	0.05
1100	0.4	0.00	0.20	0.00	2.3	1.5	0.10	0.10	0.05	0.06
1130	0.3	0.01	0.19	0.00	2.6	1.5	0.12	0.12	0.06	0.06
1200	0.1	0.03	0.18	0.00	2.4	1.5	0.13	0.13	0.05	0.05
1230	0.4	0.03	0.19	0.00	2.3	1.5	0.14	0.13	0.06	0.06
1300	0.2	0.03	0.18	0.00	2.2	1.4	0.13	0.12	0.07	0.07
1330	0.4	0.01	0.18	0.00	2.4	1.4	0.13	0.13	0.06	0.06
1400	0.2	0.01	0.18	0.00	1.4	1.4	0.10	0.18	0.07	0.08
1430	0.1	0.02	0.16	0.00	2.2	1.4	0.17	0.17	0.07	0.06
1500	0.1	0.00	0.15	0.00	2.5	1.2	0.13	0.17	0.06	0.05
1530	0.2	0.02	0.15	0.00	2.5	1.3	0.13	0.13	0.06	0.06
1600	0.1	0.03	0.14	0.00	2.6	1.2	0.15	0.11	0.06	0.07
1630	0.3	0.01	0.14	0.00	2.4	1.3	0.14	0.09	0.06	0.06
1700	0.2	0.03	0.13	0.00	2.5	1.2	0.10	0.12	0.06	0.05
1730	0.2	0.02	0.19	0.00	2.5	1.5	0.10	0.10	0.06	0.05
1800	0.2	0.01	0.19	0.00	2.4	1.3	0.10	0.14	0.07	0.05
1830	0.2	0.01	0.18	0.00	2.4	1.5	0.10	0.12	0.06	0.05
1900	0.1	0.01	0.18	0.00	4.2	1.4	0.08	0.12	0.07	0.05

Table B4

Lake Greeson 48-Hour Generation

Station A Sampling

Sample	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
1	9-12-87	0715	12.9	4.9	6.2	33
2	9-12-87	0807	12.1	5.7	6.3	33
3	9-12-87	0904	13.9	4.4	5.9	33
4	9-12-87	1000	14.2	4.4	6.2	33
5	9-12-87	1100	14.0	4.4	6.2	33
6	9-12-87	1500	14.2	4.6	6.2	33
7	9-12-87	2010	14.0	4.6	6.1	33
8	9-12-87	2230	14.1	4.9	6.1	34
9	9-13-87	0552	14.0	4.4	6.4	33
10	9-13-87	1000	14.4	4.6	6.8	33
11	9-13-87	1407	14.9	4.6	6.2	33
12	9-13-87	1800	14.2	4.7	6.2	33
13	9-13-87	2240	14.0	4.4	6.1	34
14	9-14-87	0415	13.6	5.1	5.9	34

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ
1	1.3	8	9	3.9	4.3	2.6	2
2	1.5	18	10	4.8	3.8	2.8	4
3	1.1	10	10	6.9	6.3	2.8	2
4	1.5	22	11	4.3	4.6	3.0	5
5	1.0	9	11	4.0	4.6	2.9	3
6	1.4	8	11	3.8	5.2	2.0	2
7	0.9	9	12	4.1	4.4	2.2	1
8	1.3	8	11	4.1	4.3	3.0	4
9	0.8	9	10	3.4	3.3	1.8	5
10	1.0	10	11	3.6	5.5	2.9	2
11	1.3	9	4	2.8	2.9	3.1	0
12	0.8	9	7	3.2	3.6	3.0	1
13	1.1	11	11	3.6	2.6	3.4	1
14	1.0	9	10	4.1	3.1	3.2	1

(Continued)

Table B4 (Concluded)

Sample	TP mg/ℓ	DP mg/ℓ	SRP mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ
1	0.009	0.006	0.000	0.1	0.2	0.00	0.23
2	0.018	0.004	0.000	0.1	0.1	0.01	0.20
3	0.020	0.006	0.000	0.7	0.1	0.22	0.17
4	0.008	0.006	0.000	0.1	0.1	0.04	0.19
5	0.016	0.005	0.000	0.1	0.2	0.02	0.17
6	0.043	0.005	0.000	0.2	0.2	0.08	0.16
7	0.005	0.004	0.000	0.1	0.1	0.03	0.16
8	0.023	0.005	0.000	0.1	0.2	0.03	0.17
9	0.009	0.010	0.000	0.1	0.2	0.01	0.17
10	0.005	0.005	0.000	0.1	0.1	0.02	0.16
11	0.010	0.006	0.000	0.1	0.3	0.01	0.18
12	0.009	0.002	0.000	0.1	0.1	0.01	0.18
13	0.009	0.003	0.000	0.1	0.1	0.02	0.18
14	0.009	0.003	0.000	0.1	0.2	0.01	0.18

	SS mg/ℓ	SO$_4$= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
1	0.0	2.9	1.4	0.08	0.03	0.09	0.10
2	0.0	2.6	1.7	0.06	0.01	0.12	0.10
3	0.0	2.7	1.4	0.06	0.01	0.10	0.09
4	0.0	2.5	1.5	0.07	0.04	0.09	0.08
5	0.0	2.5	1.4	0.07	0.04	0.10	0.09
6	0.0	2.8	1.5	0.09	0.05	0.11	0.09
7	0.0	2.5	1.5	0.08	0.05	0.10	0.08
8	0.0	2.6	1.7	0.07	0.03	0.10	0.10
9	0.0	2.6	1.6	0.08	0.00	0.04	0.09
10	0.0	2.7	1.7	0.03	0.00	0.10	0.09
11	0.0	2.6	1.7	0.04	0.01	0.11	0.09
12	0.0	2.7	1.6	0.05	0.02	0.11	0.09
13	0.0	2.6	1.6	0.07	0.02	0.11	0.09
14	0.0	2.6	1.6	0.05	0.02	0.11	0.10

Table B5

Lake Greeson 48-Hour Generation

High Flow Time of Travel

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	9-12-87	1100	14.0	4.4	6.15	33
B	9-12-87	1130	14.0	5.0	6.2	34
BC	9-12-87	1230	14.5	6.2	6.2	34
C	9-12-87	1300	14.3	6.4	6.3	34
D	9-12-87	1600	15.4	8.1	6.4	34
E	9-12-87	1830	16.0	8.4	6.3	34
F	9-12-87	2250	19.2	7.9	6.3	35
F2	9-13-87	0730	15.5	8.3	6.8	34

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ
A	1.0	9	11	4.0	4.6	2.9	3
B	1.1	9	10	4.3	4.2	2.6	1
BC	1.4	9	10	4.6	7.7	2.4	1
C	1.0	8	8	4.2	5.0	2.3	2
D	1.0	9	5	3.8	5.4	2.6	1
E	1.4	9	4	3.5	4.6	1.9	0
F	2.2	9	5	3.9	4.6	2.0	1
F2	2.2	10	4	3.3	2.9	2.4	1

(Continued)

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Table B5 (Concluded)

Sample	TP mg/ℓ	DP mg/ℓ	SRP mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	0.016	0.005	0.000	0.1	0.2	0.02	0.17
B	0.025	0.005	0.000	0.2	0.1	0.11	0.17
BC	0.020	0.007	0.000	0.1	0.1	0.04	0.17
C	0.040	0.007	0.000	0.1	0.1	0.03	0.17
D	0.017	0.005	0.000	0.1	0.1	0.05	0.18
E	0.012	0.003	0.000	0.1	0.1	0.02	0.17
F	0.017	0.004	0.000	0.1	0.1	0.23	0.14
F2	0.022	0.003	0.000	0.2	0.1	0.01	0.15

	SS mg/ℓ	SO_4= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	0.0	2.5	1.4	0.07	0.04	0.10	0.09
B	0.0	2.5	1.4	0.06	0.03	0.09	0.08
BC	0.0	2.3	1.4	0.07	0.04	0.09	0.07
C	0.0	3.0	1.4	0.07	0.05	0.08	0.07
D	0.0	2.5	1.4	0.09	0.05	0.07	0.05
E	0.0	2.9	1.4	0.06	0.01	0.06	0.05
F	0.0	2.5	1.8	0.09	0.02	0.05	0.04
F2	0.0	2.6	1.6	0.05	0.03	0.01	0.00

Table B6

Lake Greeson 48-Hour Generation

High Flow Steady State

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	9-14-87	0415	13.6	5.1	5.9	34
B	9-14-87	0420	13.8	4.8	6.0	34
BC	9-14-87	0350	13.8	6.0	6.1	34
C	9-14-87	0430	13.8	6.1	6.1	34
D	9-14-87	0440	13.9	6.8	6.6	34
E	9-14-87	0445	14.2	7.9	6.4	34
F	9-14-87	0435	16.0	8.0	6.7	34
G	9-14-87	0420	17.3	8.3	6.6	34
H	9-14-87	0404	17.7	8.2	6.6	35

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	DOC mg/ℓ	TIC mg/ℓ	SS mg/ℓ
A	1.0	9	10	4.1	3.1	3.2	1
B	1.7	9	8	3.3	3.3	3.1	2
BC	0.8	8	7	4.1	3.0	3.4	0
C	1.7	9	8	4.0	2.7	3.3	1
D	1.4	10	5	3.9	2.7	2.6	1
E	0.9	9	5	3.2	3.1	2.2	1
F	0.9	12	4	4.6	3.2	2.4	1
G	2.4	10	3	3.5	4.2	2.1	2
H	4.0	9	4	4.0	3.7	2.2	1

(Continued)

Table B6 (Concluded)

Sample	TP mg/ℓ	DP mg/ℓ	SRP mg/ℓ	T.TKN mg/ℓ	D.TKN mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ
A	0.009	0.003	0.000	0.1	0.2	0.01	0.18
B	0.015	0.003	0.000	0.1	0.0	0.02	0.18
BC	0.012	0.002	0.000	0.4	0.1	0.01	0.18
C	0.016	0.005	0.000	0.1	0.1	0.01	0.18
D	0.026	0.005	0.000	0.0	0.1	0.00	0.18
E	0.021	0.006	0.000	0.1	0.0	0.01	0.18
F	0.015	0.005	0.000	0.0	0.1	0.00	0.16
G	0.011	0.005	0.000	0.1	0.1	0.00	0.16
H	0.023	0.006	0.000	0.2	0.1	0.01	0.15

	S= mg/ℓ	SO$_4$= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	0.0	2.6	1.6	0.05	0.02	0.11	0.10
B	0.0	2.6	1.6	0.07	0.05	0.11	0.08
BC	0.0	2.6	1.7	0.06	0.00	0.10	0.07
C	0.0	2.7	1.7	0.05	0.00	0.09	0.06
D	0.0	2.7	1.6	0.07	0.01	0.06	0.05
E	0.0	2.7	1.6	0.06	0.02	0.02	0.04
F	0.0	2.7	1.6	0.07	0.04	0.04	0.02
G	0.0	2.9	1.6	0.15	0.05	0.04	0.01
H	0.0	2.6	1.6	0.15	0.06	0.03	0.01

Table B7
Lake Greeson 6-Hour Generation
Time of Travel Tailwater Study

Station	Time	Temperature °C	DO mg/ℓ	pH	SC μsec	Turbidity NTU	Alkalinity mg/ℓ

October 14, 1987

Station	Time	Temperature °C	DO mg/ℓ	pH	SC μsec	Turbidity NTU	Alkalinity mg/ℓ
A	0750	11.0	4.3	6.1	42	1.8	9
A-1	0900	15.2	5.2	6.2	36	2.0	9
B	0925	15.0	5.5	6.2	37	2.2	9
C	1035	13.0	8.2	6.2	36	2.0	8
D	1330	14.3	9.2	6.5	34	1.8	9
E	1520	14.2	9.4	6.5	36	1.8	9

Station	CO_2 mg/ℓ	TOC mg/ℓ	TP mg/ℓ	SRP mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	8	3.7	0.009	0.000	0.1	0.01	0.21
A-1	4	4.5	0.007	0.000	0.2	0.02	0.12
B	4	4.2	0.007	0.000	0.2	0.02	0.12
C	3	3.7	0.010	0.000	0.1	0.03	0.17
D	3	4.8	0.009	0.000	0.1	0.02	0.16
E	2	3.9	0.011	0.000	0.2	0.02	0.17

Station	S= mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	0.0	0.09	0.03	0.26	0.25
A-1	0.0	0.07	0.04	0.20	0.18
B	0.0	0.07	0.08	0.19	0.17
C	0.0	0.07	0.08	0.19	0.17
D	0.0	0.11	0.02	0.10	0.08
E	0.0	0.09	0.05	0.10	0.07

Table B8

Lake Greeson 6-Hour Generation

Steady State Tailwater Study

Station	Time	Temperature °C	DO mg/ℓ	pH	SC μsec	Turbidity NTU	Alkalinity mg/ℓ

October 14, 1987

Station	Time	Temperature °C	DO mg/ℓ	pH	SC μsec	Turbidity NTU	Alkalinity mg/ℓ
A	1400	15.3	5.1	6.2	39	2.0	10
B	1410	15.5	5.4	6.2	35	1.7	9
C	1400	16.5	6.7	6.2	34	1.8	9
D	1415	14.9	8.5	6.5	36	1.8	10

Station	CO_2 mg/ℓ	TOC mg/ℓ	TP mg/ℓ	SRP mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	7	4.4	0.017	0.000	0.3	0.03	0.14
B	6	5.2	0.007	0.000	0.2	0.03	0.15
C	5	4.6	0.011	0.000	0.2	0.03	0.14
D	2	4.2	0.007	0.000	0.2	0.01	0.15

Station	S= mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	0.0	0.09	0.06	0.21	0.17
B	0.0	0.07	0.05	0.19	0.17
C	0.0	0.04	0.01	0.15	0.12
D	0.0	0.04	0.02	0.11	0.08

Table B9

Lake Greeson, 10 Day BOD

Depth m	BOD mg/ℓ	TOC mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ	S= mg/ℓ	D.Fe mg/ℓ	D.Mn mg/ℓ
			Day 0 (August 25, 1987)				
3a	--	10.5	0.02	0.02	0.02	0.13	0.00
b	--	8.6	0.02	0.03	0.02	0.12	0.00
c	--	9.6	0.02	0.01	0.02	--	0.00
x	--	9.6	0.02	0.02	0.02	0.12	0.00
9a	--	5.0	0.03	0.14	0.00	0.14	0.06
b	--	4.8	0.02	0.13	0.00	0.17	0.06
c	--	5.3	0.02	0.13	0.00	--	0.06
x	--	5.0	0.02	0.13	0.00	0.16	0.06
41a	--	10.6	0.75	0.02	0.02	6.6	1.99
b	--	10.7	0.81	0.02	0.02	5.5	1.98
c	--	11.6	0.78	0.02	0.02	6.0	1.95
x	--	11.4	0.78	0.02	0.02	6.0	1.97
			Day 1 (August 26, 1987)				
3a	0.4	8.3	0.00	0.01	0.01	0.03	0.00
b	0.3	8.1	0.01	0.01	0.01	0.04	0.00
c	0.3	8.8	0.01	0.01	0.01	0.04	0.00
x	0.3	8.4	0.01	0.01	0.01	0.04	0.00
9a	0.3	6.6	0.00	0.14	0.00	0.07	0.06
b	0.5	6.1	0.00	0.14	0.00	0.06	0.06
c	0.4	--	0.01	0.14	0.00	0.07	0.06
x	0.4	6.3	0.00	0.14	0.00	0.07	0.06
41a	0.1	11.1	0.77	0.02	0.01	2.43	2.02
b	0.1	10.7	0.79	0.02	0.01	3.39	2.00
c	0.1	10.6	0.82	0.02	0.01	2.87	2.03
x	0.1	10.8	0.79	0.02	0.01	2.90	2.02
			Day 3 (August 28, 1987)				
3a	0.2	8.7	0.01	0.02	0.02	0.00	0.00
b	0.1	8.8	0.02	0.01	0.01	0.00	0.01
c	0.2	9.5	0.02	0.01	0.01	0.00	0.00
x	0.2	9.0	0.02	0.01	0.01	0.00	0.00

(Continued)

(Sheet 1 of 3)

Depth m	BOD mg/ℓ	TOC mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	S= mg/ℓ	D.Fe mg/ℓ	D.Mn mg/ℓ

Day 3 (August 28, 1987) (Continued)

9a	0.0	6.8	0.00	0.14	0.00	0.02	0.06
b	0.2	7.5	0.01	0.14	0.00	0.02	0.05
c	0.2	6.9	0.01	0.15	0.00	0.03	0.05
x	0.1	7.1	0.01	0.14	0.00	0.02	0.06
41a	0.2	12.7	0.78	0.02	0.01	1.80	2.04
b	0.4	11.4	0.79	0.02	0.01	2.00	2.08
c	0.2	10.8	0.80	0.03	0.01	2.40	1.96
x	0.3	11.6	0.79	0.02	0.01	2.03	2.03

Day 5 (August 30, 1987)

3a	0.8	8.7	0.02	0.01	0.01	0.00	0.00
b	0.9	7.9	0.01	0.01	0.01	0.00	0.00
c	0.8	8.4	0.02	0.01	0.01	0.00	0.00
x	0.8	8.4	0.02	0.01	0.01	0.00	0.00
9a	0.4	5.8	0.00	0.13	0.00	0.00	0.05
b	0.4	5.0	0.01	0.13	0.00	0.00	0.05
c	0.5	5.9	0.00	0.13	0.00	0.00	0.05
x	0.4	5.5	0.00	0.13	0.00	0.00	0.05
41a	1.1	12.4	0.83	0.02	0.01	3.26	2.04
b	1.2	11.5	0.83	0.02	0.01	3.00	2.00
c	1.1	11.3	0.81	0.02	0.01	2.65	2.05
x	1.1	11.7	0.82	0.02	0.01	2.97	2.03

Day 8 (September 2, 1987)

3a	1.0	7.4	0.03	0.01	0.00	0.00	0.00
b	0.9	7.3	0.03	0.01	0.00	0.00	0.00
c	0.8	8.0	0.03	0.00	0.01	0.00	0.01
x	0.9	7.6	0.03	0.01	0.00	0.00	0.00
9a	0.3	5.0	0.03	0.13	0.00	0.00	0.07
b	0.2	4.9	0.02	0.13	0.00	0.00	0.06
c	0.1	4.8	0.03	0.13	0.00	0.00	0.06
x	0.2	4.9	0.03	0.13	0.00	0.00	0.06

(Continued)

(Sheet 2 of 3)

Depth m	BOD mg/ℓ	TOC mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ	S= mg/ℓ	D.Fe mg/ℓ	D.Mn mg/ℓ
Day 8 (September 2, 1987) (Continued)							
41a	1.4	9.5	0.86	0.00	0.01	3.40	1.78
b	1.3	9.6	0.86	0.00	0.02	5.66	1.97
c	1.2	10.7	0.83	0.00	0.01	5.50	2.04
x	1.3	9.9	0.85	0.00	0.01	4.85	1.93
Day 10 (September 4, 1987)							
3a	1.1	8.1	0.03	0.01	0.00	0.06	0.02
b	1.0	8.2	0.03	0.01	0.00	0.04	0.01
c	0.7	--	0.03	0.01	0.00	0.03	0.00
x	0.9	8.2	0.03	0.01	0.00	0.04	0.01
9a	1.9	5.2	0.08	0.15	0.00	0.04	0.06
b	1.8	6.2	0.10	0.15	0.00	0.03	0.08
c	2.1	--	0.09	0.14	0.00	0.00	0.06
x	1.9	5.7	0.09	0.15	0.00	0.02	0.07
41a	1.9	10.2	0.84	0.02	0.00	3.85	1.64
b	1.7	10.1	0.87	0.03	0.00	4.08	1.95
c	1.8	10.6	0.85	0.02	0.00	4.10	1.69
x	1.8	10.3	0.85	0.02	0.00	4.01	1.76

(Sheet 3 of 3)

Table B10

Lake Greeson 10-Day BOD

Depth m	BOD mg/ℓ	TOC mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	S= mg/ℓ	SO_4= mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ
Day 0 (November 4, 1987)								
4a	--	--	0.02	0.00	0.00	2.8	0.06	0.02
b	--	5.1	0.02	0.00	0.00	2.7	0.06	0.02
x	--	5.1	0.02	0.00	0.00	2.8	0.06	0.02
14a	--	4.1	0.03	0.12	0.00	2.7	0.20	0.05
b	--	3.5	0.02	0.12	0.00	2.7	0.20	0.05
x	--	3.8	0.02	0.12	0.00	2.7	0.20	0.05
39a	--	9.2	1.2	0.00	0.00	0.9	14.5	14.0
b	--	8.8	1.2	0.01	0.00	1.0	14.8	14.4
x	--	9.0	1.2	0.00	0.00	1.0	14.6	14.2
Day 2 (November 6, 1987)								
4a	0.7	4.5	0.02	0.00	0.00	1.7	0.05	0.03
b	0.7	3.6	0.02	0.00	0.00	1.7	0.01	0.03
x	0.7	4.0	0.02	0.00	0.00	1.7	0.03	0.03
14a	0.8	3.7	0.02	0.12	0.00	1.7	0.12	0.05
b	0.7	3.5	0.02	0.12	0.00	1.7	0.10	0.04
x	0.8	3.6	0.02	0.12	0.00	1.7	0.11	0.04
39a	2.8	9.0	1.1	0.01	0.00	2.0	14.4	6.9
b	2.7	8.9	1.1	0.01	0.00	2.0	15.0	8.2
x	2.8	9.0	1.1	0.01	0.00	2.0	14.7	7.6
Day 5 (November 9, 1987)								
4a	0.6	3.6	0.02	0.02	0.00	2.6	0.08	0.01
b	0.6	3.6	0.02	0.01	0.00	3.0	0.04	0.01
x	0.6	3.6	0.02	0.02	0.00	2.8	0.06	0.01
14a	0.3	3.1	0.02	0.14	0.00	2.6	0.16	0.03
b	0.5	3.3	0.03	0.14	0.00	3.0	0.17	0.04
x	0.4	3.2	0.02	0.14	0.00	2.8	0.16	0.04

(Continued)

Table B10 (Concluded)

Depth m	BOD mg/ℓ	TOC mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ	S= mg/ℓ	SO$_4$= mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ
Day 5 (November 9, 1987) (Continued)								
39a	2.8	8.4	1.0	0.02	0.00	1.4	15.3	7.2
b	2.7	8.3	1.0	0.01	0.00	1.2	15.0	8.0
x	2.8	8.4	1.0	0.02	0.00	1.3	15.2	7.6
Day 7 (November 11, 1987)								
4a	0.6	4.4	0.02	0.00	0.00	2.6	0.03	0.03
b	0.5	4.3	0.02	0.00	0.00	2.2	0.04	0.03
x	0.6	4.4	0.02	0.00	0.00	2.4	0.04	0.03
14a	0.4	3.7	0.01	0.12	0.00	2.4	0.12	0.04
b	0.3	3.7	0.01	0.13	0.00	2.4	0.13	0.04
x	0.4	3.7	0.01	0.12	0.00	2.4	0.12	0.04
39a	3.4	9.6	1.0	0.00	0.00	1.0	15.3	12.4
b	3.3	9.9	1.0	0.00	0.00	1.2	15.1	12.5
x	3.4	9.8	1.0	0.00	0.00	1.1	15.2	12.4
Day 9 (November 13, 1987)								
4a	1.4	3.4	0.03	0.01	0.00	3.1	0.07	0.04
b	1.2	3.5	0.04	0.01	0.00	3.0	0.07	0.03
x	1.3	3.4	0.04	0.01	0.00	3.0	0.07	0.04
14a	1.3	2.8	0.02	0.13	0.00	3.0	0.11	0.04
b	1.3	3.1	0.03	0.13	0.00	3.0	0.09	0.03
x	1.3	3.0	0.02	0.13	0.00	3.0	0.10	0.04
39a	3.4	8.6	0.8	0.01	0.00	1.2	14.8	12.4
b	3.8	8.5	1.0	0.01	0.00	1.3	14.2	6.7
x	3.6	8.6	0.9	0.01	0.00	1.2	14.5	9.6

Table B11

Lake Nimrod Profile

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
		April 7, 1988, 1240 hr		
0	19.3	9.6	6.5	41
1	18.4	9.4	6.7	41
2	17.8	9.1	6.7	41
3	17.7	9.0	6.7	41
4	17.7	8.9	6.7	41
5	17.7	8.9	6.7	41
6	17.6	8.9	6.7	40
7	17.6	8.9	6.7	40
8	17.5	8.9	6.7	40
9	17.5	8.9	6.7	40
10	17.4	8.9	6.7	40
11	17.4	8.8	6.7	40
12	17.4	8.8	6.7	40
12.9	17.4	8.7	6.6	40
		May 17, 1988, 1435 hr		
0	27.0	8.2	- -	- -
1	26.1	7.9	- -	- -
2	24.4	7.0	- -	- -
3	23.0	5.2	- -	- -
4	21.5	3.9	- -	- -
5	20.4	3.7	- -	- -
6	20.0	3.3	- -	- -
7	19.0	2.8	- -	- -
8	18.6	2.4	- -	- -
9	18.2	1.9	- -	- -
10	18.1	2.0	- -	- -
11	17.8	1.6	- -	- -

(Continued)

(Sheet 1 of 5)

Table B11 (Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
		June 9, 1988, 1040 hr		
0	28.2	8.2	7.2	46
1	27.7	8.0	7.1	46
2	25.7	7.0	6.9	45
3	23.5	5.0	6.6	46
4	23.0	4.2	6.4	46
5	22.8	3.6	6.3	47
6	22.6	3.1	6.2	47
7	22.4	2.5	6.1	48
8	21.8	1.1	6.0	51
9	21.4	0.3	6.0	53
10	20.7	0.2	6.0	57
		July 5, 1988, 1050 hr		
0	28.0	--	6.1	25
1	27.1	--	6.1	24
2	26.8	--	6.0	24
3	26.6	--	6.0	24
4	26.5	--	5.9	24
5	25.2	--	5.8	27
6	24.1	--	5.8	34
7	23.8	--	5.8	35
8	23.0	--	6.0	38
9	22.3	--	6.0	42
10	21.4	--	6.2	43
11	20.6	--	6.2	46

(Continued)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec

July 18, 1988, 0715 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	29.4	7.3	6.4	52
1	29.3	7.3	6.4	52
2	29.2	6.6	6.5	52
3	28.8	5.3	6.4	52
4	27.3	2.0	6.2	55
5	26.2	0.4	6.1	57
6	25.4	0.4	6.1	67
7	23.9	0.4	6.1	84
8	23.4	0.3	6.2	87
9	22.7	0.3	6.4	87
10	21.8	0.3	6.4	89
11	21.0	0.3	6.5	93

July 20, 1988, 1145 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	29.6	6.9	6.1	54
1	29.5	6.8	6.3	52
2	29.5	6.5	6.4	52
3	29.5	6.3	6.4	52
4	29.4	6.1	6.4	52
5	29.3	5.3	6.4	53
6	27.4	0.8	6.1	54
7	25.9	0.2	6.1	66
8	24.6	0.2	6.2	80
9	23.2	0.2	6.3	90
10	21.9	0.2	6.4	92
11	21.0	0.2	6.5	98

(Continued)

(Sheet 3 of 5)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
		July 20, 1988, 1700 hr		
0	29.9	7.6	6.8	53
1	29.9	7.5	6.9	52
2	29.9	7.4	6.9	52
3	29.9	7.3	6.9	52
4	29.9	7.3	6.9	52
5	29.9	7.2	6.9	53
6	29.9	7.2	6.9	52
7	29.9	7.2	6.9	52
8	26.1	0.3	6.3	57
9	23.4	0.3	6.4	89
10	21.7	0.3	6.5	95
11	21.0	0.2	6.5	99
		July 21, 1988, 0920 hr		
0	28.9	6.8	6.5	53
1	28.9	6.7	6.6	52
2	28.9	6.6	6.6	52
3	28.9	6.6	6.6	52
4	28.9	6.6	6.6	52
5	28.9	6.4	6.6	52
6	27.0	0.4	6.3	60
7	26.2	0.3	6.2	67
8	25.6	0.3	6.3	72
9	24.3	0.3	6.3	81
10	21.8	0.3	6.4	96

(Continued)

(Sheet 4 of 5)

Table B11 (Concluded)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
		July 22, 1988, 1100 hr		
0	29.6	8.0	7.3	49
1	29.6	7.9	7.3	49
2	29.3	7.3	7.3	49
3	29.2	7.1	7.2	48
4	29.0	5.7	7.0	48
5	27.7	0.6	6.7	54
6	26.8	0.2	6.5	61
7	25.9	0.2	6.4	68
8	24.2	0.2	6.4	84
9	23.2	0.2	6.5	90
10	21.8	0.2	6.6	97

(Sheet 5 of 5)

Table B12

Lake Nimrod Pre-generation Lake Sampling*

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
			July 18, 1988, 0715 hr				
0	7.2	12	3	5.7	0.5	0.03	0.03
2	7.1	12	3	5.5	0.5	0.04	0.00
4	9.2	12	8	5.5	0.8	0.13	0.00
6	32.	19	10	5.0	0.9	0.36	0.00
8	30.	32	17	5.6	1.3	0.77	0.01
10	30.	30	20	6.2	3.1	0.80	0.00
11	31.	30	22	7.8	1.9	1.34	0.01

Depth	SO_4= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
0	2.3	2.3	0.21	0.05	0.11	0.02
2	3.1	2.4	0.22	0.05	0.12	0.02
4	2.8	2.5	0.37	0.05	0.26	0.06
6	2.3	2.4	1.80	0.14	2.51	2.26
8	0.3	2.5	4.43	2.82	3.94	3.72
10	0.3	2.6	5.42	3.92	3.68	3.46
11	0.4	2.2	6.96	4.71	3.69	3.80

(Continued)

* Pool elevation at 105.04 m.

Table B12 (Concluded)

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
		July 21, 1988, 0920 hr					
0	14.	11	3	5.4	0.5	0.02	0.00
2	14.	12	4	4.8	0.5	0.03	0.00
4	13.	12	3	5.1	0.5	0.03	0.00
6	16.	12	4	5.4	0.5	0.06	0.00
8	35.	18	12	5.8	0.9	0.32	0.00
10	41.	28	16	7.4	1.2	0.72	0.00

	$SO_4^=$ mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
0	3.4	2.1	0.24	0.00	0.16	0.04
2	3.2	2.1	0.25	0.01	0.16	0.03
4	2.9	2.0	0.24	0.01	0.16	0.03
6	3.2	2.2	0.32	0.03	0.25	0.10
8	2.6	2.4	1.40	0.08	1.87	1.74
10	1.0	2.3	3.72	2.14	3.44	3.32

Table B13
Lake Nimrod Tailwater Low Flow
(20 cfs) Steady State

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC µsec
A	7-18-88	1235	25.1	6.9	6.5	74
B	7-18-88	1225	25.5	6.3	6.3	71
B-3	7-18-88	1200	28.7	6.4	6.1	65
C	7-18-88	1140	30.6	6.2	6.2	63
D	7-18-88	1100	31.2	6.4	6.2	58

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	38.	25	8	11.2	1.3	0.70	0.08
B	27.	24	8	4.8	0.9	0.53	0.13
B-3	21.	19	8	5.9	0.4	0.22	0.30
C	13.	17	6	5.9	0.4	0.08	0.34
D	6.4	15	6	6.8	0.4	0.04	0.26

	$SO_4^=$ mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	1.0	2.4	4.41	0.91	3.75	3.15
B	1.6	2.4	2.88	0.50	3.17	2.91
B-3	1.6	2.0	2.50	0.56	1.96	1.38
C	1.9	2.4	1.63	0.49	0.91	0.70
D	1.9	2.2	1.08	0.49	0.25	0.15

Table B14

Lake Nimrod Tailwater High Flow

(200 cfs) Time of Travel

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	7-20-88	1220	25.6	7.6	6.2	69
B	7-20-88	1425	26.1	7.2	6.4	68
B-2	7-20-88	1620	26.6	6.6	6.4	66
B-3	7-20-88	1820	26.3	6.5	6.5	66
C	7-21-88	0345	25.2	6.0	6.4	63
D	7-21-88	1645	28.9	7.2	6.7	55

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	32.	21	6	6.1	0.9	0.41	0.02
B	32.	20	8	8.0	0.9	0.41	0.03
B-2	27.	21	9	8.5	0.8	0.39	0.06
B-3	31.	19	7	5.1	0.8	0.34	0.09
C	20.	18	6	5.5	0.6	0.21	0.12
D	17.	15	4	5.7	0.6	0.09	0.13

	SO_4= mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	1.8	2.4	2.29	0.62	2.32	2.23
B	1.9	2.2	2.22	0.64	2.34	2.16
B-2	1.8	2.4	2.14	0.54	2.26	2.10
B-3	1.9	2.3	2.26	0.52	2.33	1.87
C	2.3	2.4	1.54	0.54	1.28	1.14
D	2.8	2.0	1.22	0.36	0.70	0.57

Table B15

Lake Nimrod Tailwater High Flow

(200 cfs) Steady State

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	7-22-88	0925	24.4	7.3	6.7	68
B	7-22-88	0915	24.4	6.9	6.7	66
B-2	7-22-88	0900	23.7	6.5	6.7	67
B-3	7-22-88	0835	23.5	6.7	6.7	67
C	7-22-88	0815	23.8	6.2	6.6	63
D	7-22-88	0750	25.2	6.1	6.5	58
E	7-22-88	0730	25.8	6.0	6.5	57

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	39.	20	6	6.5	1.1	0.57	0.12
B	35.	22	6	5.8	1.1	0.55	0.03
B-2	30.	23	6	5.8	1.1	0.56	0.06
B-3	30.	23	6	5.5	1.1	0.50	0.10
C	24.	19	6	6.2	0.9	0.38	0.13
D	20.	17	6	5.3	0.6	0.22	0.17
E	18.	17	6	5.9	0.5	0.15	0.19

	$SO_4^=$ mg/ℓ	Cl- mg/ℓ	T.Fe mg/ℓ	D.Fe mg/ℓ	T.Mn mg/ℓ	D.Mn mg/ℓ
A	2.2	2.4	3.23	0.90	2.76	2.46
B	1.5	2.2	3.19	0.91	2.65	2.53
B-2	1.5	2.3	3.26	1.05	2.64	2.53
B-3	1.7	2.2	3.20	1.10	2.53	2.25
C	2.3	2.2	2.29	0.84	1.70	1.56
D	2.3	2.0	1.52	0.50	1.00	0.88
E	2.2	2.2	1.48	0.58	0.89	0.72

Table B16

Lake Nimrod 10-Day BOD

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ
Day 0 (July 6, 1988)							
2a	--	7.0	0.6	0.07	0.07	0.00	3.0
b	--	7.0	1.0	0.07	0.07	0.00	3.1
c	--	6.8	0.6	0.07	0.04	0.00	3.2
x	--	6.9	0.7	0.07	0.06	0.00	3.1
6a	--	6.4	0.8	0.20	0.03	0.00	2.8
b	--	7.4	0.8	0.21	0.03	0.00	2.8
c	--	7.5	0.8	0.21	0.07	0.00	2.7
x	--	7.1	0.8	0.21	0.04	0.00	2.8
10a	--	7.7	1.2	0.45	0.11	0.00	2.3
b	--	7.6	1.1	0.46	0.07	0.00	2.4
c	--	7.2	1.1	0.46	0.07	0.00	2.2
x	--	7.5	1.1	0.46	0.08	0.00	2.3

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
2a	0.28	0.06	0.23	0.01
b	0.28	0.06	0.24	0.02
c	0.29	0.06	0.24	0.01
x	0.28	0.06	0.24	0.01
6a	0.77	0.11	2.36	1.75
b	0.70	0.10	2.32	1.75
c	0.69	0.12	2.32	1.71
x	0.72	0.11	2.33	1.74
10a	3.28	1.60	3.24	2.87
b	3.24	1.65	3.24	2.85
c	3.26	1.64	3.26	2.89
x	3.26	1.63	3.25	2.87

(Continued)

(Sheet 1 of 5)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ
			Day 2 (July 8, 1988)				
2a	0.8	6.1	0.5	0.09	0.06	0.00	3.3
b	0.8	7.4	0.3	0.09	0.11	0.00	3.2
c	0.8	5.6	0.6	0.09	0.03	0.00	3.2
x	0.8	6.4	0.5	0.09	0.07	0.00	3.2
6a	0.8	7.9	0.7	0.23	0.04	0.00	3.0
b	0.8	8.6	0.7	0.23	0.04	0.00	3.0
c	0.8	8.8	0.6	0.21	0.05	0.00	2.7
x	0.8	8.4	0.7	0.22	0.04	0.00	2.9
10a	0.7	9.1	1.1	0.46	0.03	0.00	2.2
b	0.7	9.6	0.9	0.43	0.03	0.00	2.0
c	0.7	10.2	1.0	0.45	0.05	0.00	2.0
x	0.7	9.6	1.0	0.45	0.04	0.00	2.1

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
2a	0.24	0.05	0.22	0.01
b	0.23	0.07	0.20	0.01
c	0.23	0.05	0.21	0.02
x	0.23	0.06	0.21	0.01
6a	0.56	0.08	2.10	1.21
b	0.53	0.07	2.11	1.29
c	0.57	0.08	2.13	1.30
x	0.55	0.08	2.11	1.27
10a	3.02	1.50	3.02	2.67
b	2.98	1.52	3.00	2.69
c	2.96	1.51	3.02	2.69
x	2.99	1.51	3.01	2.68

(Continued)

Table B16 (Continued)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	$SO_4=$ mg/ℓ
			Day 5 (July 11, 1988)				
2a	1.7	5.6	0.6	0.15	0.04	0.00	3.5
b	1.7	7.2	0.5	0.16	0.03	0.00	3.3
c	1.7	5.4	0.6	0.15	0.04	0.00	3.1
x	1.7	6.1	0.6	0.15	0.04	0.00	3.3
6a	1.2	6.0	0.7	0.25	0.05	0.00	2.8
b	1.3	6.1	0.7	0.26	0.04	0.00	2.8
c	1.2	5.7	0.7	0.26	0.04	0.00	2.8
x	1.2	5.9	0.7	0.26	0.04	0.00	2.8
10a	1.3	8.3	1.2	0.53	0.05	0.00	2.1
b	1.2	8.0	1.1	0.50	0.05	0.00	2.1
c	1.3	7.8	1.0	0.50	0.03	0.00	2.1
x	1.3	8.0	1.1	0.51	0.04	0.00	2.1

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
2a	0.28	0.04	0.23	0.01
b	0.28	0.05	0.22	0.01
c	0.26	0.04	0.21	0.01
x	0.27	0.04	0.22	0.01
6a	0.79	0.07	2.17	0.88
b	0.74	0.09	2.10	0.85
c	0.77	0.09	2.17	0.87
x	0.77	0.08	2.15	0.87
10a	3.44	1.50	3.24	2.58
b	3.54	1.69	3.30	2.55
c	3.56	1.50	3.22	2.55
x	3.51	1.56	3.25	2.56

(Continued)

(Sheet 3 of 5)

Table B16 (Continued)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH$_3$-N ng/ℓ	NO$_3$-N mg/ℓ	NO$_2$-N mg/ℓ	SO$_4$= mg/ℓ

Day 7 (July 13, 1988)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH$_3$-N ng/ℓ	NO$_3$-N mg/ℓ	NO$_2$-N mg/ℓ	SO$_4$= mg/ℓ
2a	2.0	8.6	0.4	0.16	0.05	0.00	3.2
b	1.9	7.6	0.6	0.18	0.06	0.00	3.3
c	1.9	7.6	0.5	0.18	0.08	0.00	3.1
x	1.9	7.9	0.5	0.17	0.06	0.00	3.2
6a	1.5	7.2	0.6	0.28	0.06	0.00	2.6
b	1.5	9.2	0.6	0.28	0.09	0.00	2.8
c	1.7	9.1	0.6	0.29	0.05	0.00	2.9
x	1.6	8.5	0.6	0.28	0.07	0.00	2.8
10a	1.7	8.2	0.9	0.56	0.05	0.00	2.2
b	1.7	9.1	1.0	0.55	0.04	0.00	2.0
c	1.6	6.2	1.2	0.54	0.06	0.00	2.1
x	1.7	7.8	1.0	0.55	0.05	0.00	2.1

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
2a	0.24	0.03	0.21	0.01
b	0.24	0.03	0.20	0.02
c	0.24	0.03	0.23	0.01
x	0.24	0.03	0.21	0.01
6a	0.62	0.05	1.82	0.58
b	0.60	0.05	1.80	0.59
c	0.62	0.05	1.86	0.59
x	0.61	0.05	1.83	0.59
10a	3.28	1.65	3.13	1.99
b	3.26	1.57	3.13	1.95
c	3.28	1.57	3.16	1.88
x	3.27	1.60	3.14	1.94

(Continued)

Table B16 (Concluded)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	$SO_4=$ mg/ℓ
				Day 10 (July 16, 1988)			
2a	2.1	5.7	0.4	0.18	0.04	0.00	4.9
b	2.5	6.9	0.5	0.18	0.05	0.00	3.0
c	2.2	6.8	0.5	0.18	0.03	0.00	3.2
x	2.3	6.5	0.5	0.18	0.04	0.00	3.7
6a	2.2	6.4	0.6	0.32	0.03	0.02	2.8
b	2.0	5.4	0.6	0.27	0.04	0.03	2.8
c	1.9	9.9	0.6	0.28	0.03	0.02	2.9
x	2.0	7.2	0.6	0.29	0.03	0.02	2.8
10a	2.2	7.8	0.9	0.49	0.04	0.05	2.2
b	2.2	6.9	0.8	0.46	0.03	0.08	2.3
c	2.1	9.2	0.9	0.51	0.03	0.05	2.4
x	2.2	8.0	0.9	0.49	0.03	0.05	2.4

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
2a	0.24	0.05	0.17	0.01
b	0.24	0.05	0.15	0.02
c	0.22	0.06	0.16	0.01
x	0.23	0.05	0.16	0.01
6a	0.62	0.09	1.38	0.21
b	0.57	0.08	1.42	0.22
c	0.57	0.08	1.39	0.22
x	0.59	0.08	1.40	0.22
10a	3.12	1.55	2.84	1.77
b	3.16	1.52	2.87	1.80
c	3.06	1.54	2.73	1.55
x	3.11	1.54	2.81	1.71

Table B17

Rough River Lake Profile*

Depth m	Temperature °C	DO mg/ℓ
May 9, 1988		
0.0	18.6	9.2
1.5	18.6	9.1
3.0	18.7	8.2
4.6	18.5	7.1
6.1	15.2	5.2
7.6	14.5	2.8
9.1	13.7	2.0
10.7	12.6	1.0
12.2	12.2	1.0
13.7	11.8	1.2
15.2	11.6	1.7
16.8	11.5	2.1
May 16, 1988		
0	23.2	9.5
1.5	22.6	8.7
3.0	19.5	8.7
4.6	18.6	7.6
6.1	17.9	5.4
7.6	16.3	3.9
9.1	14.8	1.6
10.7	13.4	0.6
12.2	12.8	0.5
13.7	12.6	0.5
15.2	12.2	0.7
16.8	12.4	0.7

(Continued)

* Data furnished by US Corps of Engineers personnel - Rough River Lake Field
Office.

Depth m	Temperature °C	DO mg/ℓ
	May 22, 1988	
0	23.4	8.4
1.5	23.6	8.3
3.0	23.0	7.5
4.6	17.7	5.9
6.1	16.2	3.9
7.6	14.9	2.3
9.1	13.6	0.4
10.7	13.0	0.4
12.2	12.6	0.5
13.7	12.3	0.7
15.2	12.1	1.0
16.8	11.9	1.2
	May 30, 1988	
0	23.5	9.0
1.5	23.4	8.7
3.0	22.8	8.1
4.6	20.7	7.1
6.1	16.4	6.4
7.6	15.5	0.5
9.1	14.5	0.3
10.7	13.6	0.3
12.2	12.8	0.4
13.7	12.4	0.5
15.2	12.2	0.5
16.8	12.2	0.6

(Continued)

(Sheet 2 of 10)

Depth m	Temperature °C	DO mg/ℓ
June 6, 1988		
0	23.5	8.9
1.5	23.3	8.7
3.0	23.0	8.4
4.6	22.4	7.6
6.1	17.5	4.6
7.6	15.9	3.5
9.1	14.4	0.2
10.7	13.6	0.2
12.2	13.0	0.3
13.7	12.7	0.4
15.2	12.6	0.8
16.8	12.2	0.9
June 13, 1988		
0	23.7	8.6
1.5	24.0	8.4
3.0	23.9	6.6
4.6	23.2	5.4
6.1	18.4	0.3
7.6	16.7	0.3
9.1	15.2	0.4
10.7	14.2	0.4
12.2	13.4	0.5
13.7	13.0	0.6
15.2	12.7	0.7
16.8	12.3	0.9

(Continued)

Table B17 (Continued)

Depth m	Temperature °C	DO mg/ℓ

June 20, 1988

Depth m	Temperature °C	DO mg/ℓ
0	26.0	8.3
1.5	26.5	8.4
3.0	26.2	8.9
4.6	23.6	11.1
6.1	20.0	12.0
7.6	16.2	3.6
9.1	15.0	0.2
10.7	14.3	0.2
12.2	13.6	0.3
13.7	13.0	0.3
15.2	12.7	0.4
16.8	12.7	0.6

June 27, 1988

Depth m	Temperature °C	DO mg/ℓ
0	26.2	9.3
1.5	26.4	9.3
3.0	26.4	9.4
4.6	23.8	9.5
6.1	20.3	13.0
7.6	17.6	13.9
9.1	13.7	9.6
10.7	13.0	1.4
12.2	12.5	0.2
13.7	12.2	0.3
15.2	12.2	0.3
16.8	12.2	0.5

(Continued)

(Sheet 4 of 10)

Depth m	Temperature °C	DO mg/ℓ

July 5, 1988

Depth m	Temperature °C	DO mg/ℓ
0	25.7	9.1
1.5	25.8	9.2
3.0	25.8	9.2
4.6	24.5	9.3
6.1	19.1	10.2
7.6	15.8	9.3
9.1	14.6	0.2
10.7	13.5	0.2
12.2	13.2	0.2
13.7	12.8	0.4
15.2	12.5	0.4
16.8	12.4	0.5

July 11, 1988

Depth m	Temperature °C	DO mg/ℓ
0	28.4	9.2
1.5	28.5	9.2
3.0	27.2	9.3
4.6	24.7	9.7
6.1	22.0	10.4
7.6	17.2	9.5
9.1	14.6	4.5
10.7	13.7	0.2
12.2	13.1	0.2
13.7	12.6	0.2
15.2	12.6	0.3
16.8	12.6	0.3

(Continued)

Depth m	Temperature °C	DO mg/ℓ

July 18, 1988

Depth m	Temperature °C	DO mg/ℓ
0	29.2	8.3
1.5	29.4	8.0
3.0	27.4	7.3
4.6	25.4	5.8
6.1	21.4	2.6
7.6	17.5	0.2
9.1	15.5	0.2
10.7	13.7	0.2
12.2	13.3	0.2
13.7	12.9	0.2
15.2	12.9	0.2
16.8	13.3	0.2

July 25, 1988

Depth m	Temperature °C	DO mg/ℓ
0	27.4	9.4
1.5	27.7	8.9
3.0	27.5	7.9
4.6	26.4	6.3
6.1	23.2	3.0
7.6	19.4	0.3
9.1	17.4	0.4
10.7	15.4	0.4
12.2	14.3	0.4
13.7	13.6	0.5
15.2	13.3	0.6
16.8	12.9	0.7

(Continued)

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Table B17 (Continued)

Depth m	Temperature °C	DO mg/ℓ

August 1, 1988

0	295.7	9.5
1.5	29.8	9.8
3.0	28.6	10.8
4.6	27.2	9.3
6.1	24.3	5.2
7.6	20.8	0.1
9.1	18.2	0.1
10.7	16.1	0.1
12.2	14.9	0.1
13.7	14.2	0.1
15.2	13.8	0.1
16.8	13.5	0.1

August 8, 1988

0	29.5	8.8
1.5	29.8	8.7
3.0	26.8	8.0
4.6	23.1	3.8
6.1	20.8	2.1
7.6	16.8	0.0
9.1	15.3	0.0
10.7	14.4	0.0
12.2	14.1	0.1
13.7	13.7	0.1
15.2	13.5	0.1
16.8	13.1	0.1

(Continued)

(Sheet 7 of 10)

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec

August 11, 1988, 0910 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	30.3	8.7	8.1	192
1	30.3	8.6	8.2	192
2	30.2	9.1	8.2	192
3	29.8	10.4	8.3	192
4	28.3	11.9	8.4	218
5	26.2	8.1	8.2	236
6	24.2	2.9	7.8	247
7	22.5	0.3	7.7	245
8	19.9	0.2	7.7	248
9	18.3	0.2	7.6	248
10	16.9	0.2	7.6	248
11	15.8	0.2	7.5	248
12	15.2	0.2	7.4	253
13	15.1	0.2	7.3	256
14	14.8	0.2	7.3	257
15	14.6	0.2	7.3	259
16	14.5	0.2	7.3	260
17	14.3	0.2	7.3	260
18	14.2	0.2	7.3	263

August 15, 1988, 1630 hr

Depth m	Temperature °C	DO mg/ℓ	pH	SC μsec
0	33.0	8.1	8.3	195
1	31.8	8.6	8.4	193
2	31.4	8.6	8.4	194
3	30.5	11.3	8.5	194
4	29.0	12.6	8.5	195
5	26.4	9.0	8.4	215

(Continued)

(Sheet 8 of 10)

Depth m	Temperature °C	DO mg/ℓ	pH	SC µsec
	August 15, 1988, 1630 hr (Continued)			
6	23.9	1.2	7.7	240
7	22.0	0.3	7.7	244
8	19.8	0.2	7.7	247
9	18.2	0.2	7.6	250
10	16.9	0.2	7.5	250
11	15.9	0.2	7.4	249
12	15.4	0.2	7.3	254
13	15.2	0.2	7.3	258
14	14.9	0.2	7.3	259
15	14.8	0.2	7.2	262
16	14.5	0.2	7.2	263
17	14.3	0.2	7.2	263
18	14.3	0.2	7.2	263
	August 18, 1988, 1020 hr			
0	31.8	8.2	8.3	194
1	31.4	8.3	8.3	194
2	31.3	8.2	8.3	195
3	31.2	8.1	8.3	195
4	27.9	9.3	8.3	211
5	26.4	6.1	8.1	222
6	24.5	1.2	7.8	235
7	22.2	0.3	7.7	245
8	19.4	0.2	7.6	250
9	17.9	0.2	7.5	249
10	17.0	0.2	7.4	245
11	16.3	0.2	7.3	247

(Continued)

(Sheet 9 of 10)

Table B17 (Concluded)

Depth m	Temperature °C	DO mg/ℓ	pH	SC µsec
		August 18, 1988, 1020 hr (Continued)		
12	15.6	0.2	7.2	255
13	15.1	0.2	7.2	258
14	14.8	0.2	7.2	261
15	14.7	0.2	7.2	263
16	14.6	0.2	7.2	263
17	14.3	0.2	7.2	263

(Sheet 10 of 10)

Table B18

Rough River Reservoir Pre-Generation Lake

Sampling, August 15, 1988, 1630 hr

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
0	2.6	68	0	7.6	0.4	0.04	0.02
2	2.5	68	0	7.2	0.3	0.01	0.01
4	3.6	70	0	7.1	0.4	0.02	0.02
6	4.2	87	2	6.3	0.4	0.01	0.14
8	4.3	99	6	7.8	0.5	0.13	0.14
10	8.6	98	8	7.4	0.8	0.32	0.03
12	19.	110	12	7.0	1.2	0.70	0.00
14	31.	114	18	8.8	1.7	1.03	0.00
16	29.	121	19	8.4	1.9	1.20	0.00
17	21.	122	21	8.1	1.9	1.27	0.00

Depth m	SO_4= mg/ℓ	Cl- mg/ℓ	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
0	20.5	5.7	0.02	0.01	0.01	0.01
2	20.6	5.5	0.02	0.01	0.01	0.01
4	20.0	5.5	0.03	0.01	0.02	0.02
6	19.2	5.3	0.04	0.01	0.02	0.02
8	18.8	5.4	0.06	0.01	0.11	0.01
10	18.5	5.6	0.21	0.03	0.97	0.90
12	11.6	5.1	1.44	0.41	.94	1.80
14	8.0	5.4	2.09	0.48	.35	2.18
16	6.8	5.4	2.15	0.80	2.58	2.45
17	6.0	5.7	2.18	0.90	2.52	2.32

(Continued)

* Pool elevation at 149.98 m.

Table B18 (Concluded)

Depth m	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
0	3.5	67	0	7.0	0.3	0.01	0.02
2	2.6	68	0	6.4	0.4	0.02	0.00
4	3.3	74	0	7.6	0.5	0.03	0.00
6	2.3	84	1	7.4	0.5	0.03	0.06
8	1.5	97	5	6.4	0.4	0.09	0.16
10	5.9	100	7	6.1	0.7	0.38	0.01
12	11.	110	14	5.8	1.3	0.90	0.00
14	15.	121	16	--	1.8	1.32	0.01
16	14.	122	17	7.4	2.4	1.49	0.01

Depth m	SO_4= mg/ℓ	Cl- mg/ℓ	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
0	21.6	6.0	0.01	0.01	0.01	0.01
2	21.4	5.8	0.01	0.01	0.01	0.01
4	20.3	5.6	0.02	0.02	0.01	0.01
6	20.6	5.9	0.02	0.02	0.01	0.01
8	20.0	5.8	0.06	0.02	0.04	0.01
10	19.2	5.8	0.23	0.03	0.98	0.95
12	11.3	5.4	1.64	0.95	1.92	1.87
14	8.1	5.7	2.27	1.36	2.48	2.38
16	6.1	5.7	2.30	1.46	2.59	2.53

Table B19

Rough River Reservoir Tailwater

Low Flow, Steady State

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	8-16-88	0845	15.2	6.4	7.0	257
B	8-16-88	0900	16.4	5.2	7.2	255
C	8-16-88	0915	19.2	4.6	7.2	256
D	8-16-88	0930	24.0	4.8	7.2	237
E	8-16-88	0945	24.0	4.1	7.1	239
Ebd	8-16-88	1005	20.5	7.2	7.1	251
F	8-16-88	1100	21.8	5.6	7.1	245
G	8-16-88	1200	23.9	5.3	7.1	242
H	8-16-88	1225	25.7	5.6	7.2	238

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	22.	114	10	11.2	1.7	1.10	0.01
B	17.	114	12	9.4	1.5	0.93	0.02
C	16.	110	11	7.9	1.4	0.86	0.04
D	14.	98	8	8.2	1.4	0.64	0.11
E	14.	97	10	7.8	1.3	0.63	0.13
Ebd	17.	106	10	8.6	1.4	0.72	0.12
F	11.	103	10	10.9	1.0	0.49	0.32
G	13.	100	9	9.0	0.8	0.30	0.45
H	16.	96	8	9.1	0.6	0.15	0.54

	$SO_4^=$ mg/ℓ	Cl- mg/ℓ	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
A	10.2	5.4	1.77	0.31	2.14	2.06
B	11.5	5.5	1.50	0.21	2.14	2.00
C	10.8	5.5	1.32	0.02	1.81	0.02
D	12.7	5.3	0.69	0.08	1.27	1.11
E	13.3	5.4	0.67	0.08	1.37	1.20
Ebd	11.9	5.5	0.95	0.10	2.00	1.81
F	12.0	5.5	0.58	0.10	1.48	1.39
G	12.2	5.4	0.55	0.07	1.26	1.19
H	12.7	5.4	0.54	0.09	1.00	0.92

Table B20

Rough River Reservoir, High

Flow, Time of Travel

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	8-17-88	1400	16.0	8.5	7.1	248
A-1	8-17-88	1630	16.5	8.0	7.2	245
B	8-17-88	1930	16.3	8.1	7.3	253
C	8-18-88	0215	16.2	7.7	7.2	251
D	8-18-88	1330	17.0	6.6	7.2	247
E	8-18-88	2000	17.5	6.1	7.2	249
Ebd	8-18-88	2020	17.8	8.2	7.2	251
F	8-19-88	0030	18.0	7.6	7.3	252
G	8-19-88	0815	18.1	7.6	7.3	251

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	14.	113	12	7.5	1.5	1.11	0.01
A-1	27.	116	12	6.9	1.5	0.98	0.02
B	23.	113	13	6.8	1.6	1.07	0.01
C	26.	114	12	7.1	1.5	1.00	0.02
D	25.	114	13	6.4	1.5	1.06	0.04
E	26.	112	14	5.9	1.5	0.98	0.03
Ebd	22.	105	10	7.3	1.5	0.93	0.07
F	23.	110	10	6.1	1.8	0.92	0.11
G	32.	112	7	--	1.4	0.79	0.15

	SO_4= mg/ℓ	Cl- mg/ℓ	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
A	9.8	5.7	1.95	0.71	2.15	2.08
A-1	9.9	5.2	2.19	0.34	2.14	2.09
B	9.9	4.8	1.80	0.28	2.09	2.11
C	10.0	4.9	1.73	0.22	2.13	2.05
D	11.3	5.9	1.75	0.16	2.12	2.08
E	11.6	5.8	1.43	0.25	1.99	1.91
Ebd	11.4	5.5	1.44	0.18	1.98	1.85
F	11.5	5.6	1.34	0.23	1.79	1.67
G	11.2	5.5	1.32	0.18	1.78	1.58

Table B21

Rough River Reservoir, High
Flow, Steady State

Station	Date	Time	Temperature °C	DO mg/ℓ	pH	SC μsec
A	8-19-88	1035	15.2	8.6	7.3	255
A-1	8-19-88	1025	15.3	8.2	7.4	254
B	8-19-88	1015	15.3	8.0	7.3	254
C	8-19-88	1000	15.4	7.5	7.2	253
D	8-19-88	0940	16.5	6.7	7.3	253
E	8-19-88	0925	16.6	6.2	7.2	252
Ebd	8-19-88	0910	17.3	8.5	7.3	252
F	8-19-88	0850	17.1	7.8	7.4	252
G	8-19-88	0815	18.1	7.6	7.3	251

	Turbidity NTU	Alkalinity mg/ℓ	CO_2 mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	20.	116	14	9.4	1.7	1.06	0.01
A-1	21.	115	11	9.2	1.7	1.05	0.02
B	16.	117	12	10.9	1.7	1.04	0.02
C	22.	114	11	7.0	1.6	1.05	0.02
D	20.	114	15	6.1	1.5	1.04	0.03
E	32.	112	14	9.8	1.5	0.95	0.04
Ebd	34.	112	10	7.0	1.5	0.88	0.06
F	29.	112	9	6.9	1.5	0.86	0.11
G	32.	112	7	5.7	1.4	0.79	0.15

	SO_4= mg/ℓ	Cl- mg/ℓ	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
A	10.5	5.7	1.60	0.81	2.14	2.03
A-1	9.8	5.7	1.46	0.39	2.16	2.09
B	10.0	5.7	1.39	0.35	2.04	2.02
C	11.4	5.8	1.43	0.28	2.10	2.08
D	11.3	5.6	1.47	0.43	1.98	2.00
E	12.1	5.6	1.54	0.25	2.06	1.99
Ebd	12.1	5.7	1.40	0.19	2.04	1.96
F	11.7	5.7	1.69	0.09	2.00	1.81
G	11.2	5.5	1.32	0.18	1.78	1.58

Table B22

Rough River Reservoir

10-day BOD

Depth m	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ
			Day 0 (August 11, 1988)			
3a	7.6	0.4	0.00	0.00	0.00	22.4
b	7.8	0.6	0.03	0.00	0.00	19.0
c	7.7	0.4	0.00	0.01	0.00	19.4
x	7.7	0.5	0.01	0.00	0.00	20.3
11a	9.8	0.8	0.39	0.01	0.00	17.4
b	8.2	0.9	0.40	0.01	0.00	17.4
c	9.0	0.8	0.40	0.01	0.00	17.5
x	9.0	0.8	0.40	0.01	0.00	17.4
17a	9.8	1.8	0.98	0.00	0.00	7.4
b	10.5	1.9	1.15	0.00	0.00	7.3
c	9.7	1.8	1.23	0.00	0.00	7.3
x	10.0	1.8	1.12	0.00	0.00	7.3

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
3a	0.07	0.07	0.02	0.01
b	0.07	0.07	0.02	0.01
c	0.08	0.07	0.01	0.01
x	0.07	0.07	0.02	0.01
11a	0.32	0.10	1.22	1.10
b	0.35	0.09	1.21	1.11
c	0.32	0.13	1.20	1.01
x	0.32	0.13	1.20	1.01
17a	0.33	0.11	1.21	1.07
b	2.09	0.78	2.58	2.44
c	2.03	0.45	2.56	2.30
x	2.06	0.48	2.62	2.31

(Continued)

(Sheet 1 of 5)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ

Day 3 (August 14, 1988)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ
3a	0.4	5.2	0.4	0.05	0.01	0.00	18.7
b	0.4	5.1	0.4	0.05	0.01	0.00	18.9
c	0.4	5.4	0.4	0.02	0.01	0.00	17.6
x	0.4	5.2	0.4	0.04	0.01	0.00	18.4
11a	1.0	7.7	0.9	0.41	0.01	0.01	16.3
b	1.3	5.4	1.0	0.45	0.01	0.01	17.0
c	1.0	4.5	0.9	0.40	0.02	0.01	17.0
x	1.1	5.9	0.9	0.42	0.01	0.01	16.8
17a	2.2	10.0	1.8	1.13	0.01	0.01	8.7
b	2.1	9.4	1.7	1.16	0.01	0.01	8.8
c	2.3	10.4	1.7	1.17	0.01	0.01	8.7
x	2.2	9.9	1.7	1.15	0.01	0.01	8.7

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
3a	0.05	0.03	0.01	0.01
b	0.05	0.03	0.01	0.01
c	0.06	0.03	0.01	0.01
x	0.05	0.03	0.01	0.01
11a	0.35	0.03	1.10	0.01
b	0.35	0.02	1.07	0.01
c	0.29	0.03	0.80	0.07
x	0.33	0.03	0.99	0.03
17a	2.13	0.08	2.44	1.05
b	2.18	0.08	2.47	1.20
c	2.12	0.09	2.44	1.25
x	2.14	0.08	2.45	1.17

(Continued)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	$SO_4^=$ mg/ℓ
			Day 5 (August 16, 1988)				
3a	1.4	8.2	0.5	0.08	0.01	0.00	20.1
b	1.3	7.3	0.5	0.12	0.00	0.00	19.5
c	1.4	9.3	0.7	0.10	0.01	0.00	20.3
x	1.4	8.3	0.6	0.10	0.01	0.00	20.0
11a	1.8	7.6	0.9	0.48	0.01	0.00	17.5
b	2.2	6.0	1.1	0.54	0.01	0.02	16.7
c	1.8	9.0	0.9	0.47	0.01	0.00	16.2
x	1.9	7.5	1.0	0.50	0.01	0.01	16.8
17a	3.4	6.6	1.8	1.23	0.01	0.00	8.7
b	3.5	8.8	2.0	1.22	0.01	0.01	9.5
c	3.4	8.7	1.9	1.23	0.01	0.01	9.4
x	3.4	8.0	1.9	1.23	0.01	0.01	9.2

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
3a	0.04	0.01	0.02	0.02
b	0.04	0.02	0.02	0.02
c	0.05	0.02	0.03	0.02
x	0.04	0.02	0.02	0.02
11a	0.36	0.03	1.00	0.02
b	0.32	0.03	1.06	0.02
c	0.39	0.03	1.09	0.02
x	0.36	0.03	1.05	0.02
17a	1.16	0.11	1.60	0.84
b	2.16	0.10	2.34	0.87
c	2.16	0.11	2.24	0.85
x	1.83	0.11	2.06	0.85

(Continued)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH$_3$-N mg/ℓ	NO$_3$-N mg/ℓ	NO$_2$-N mg/ℓ	SO$_4$= mg/ℓ
				Day 7 (August 18, 1988)			
3a	1.3	6.4	--	0.08	0.00	0.00	21.2
b	1.3	6.6	0.4	0.10	0.00	0.00	21.1
c	1.6	6.4	0.5	0.13	0.01	0.00	21.3
x	1.4	6.5	0.4	0.10	0.00	0.00	21.2
11a	2.0	5.8	0.9	0.56	--	--	--
b	2.1	5.6	1.0	0.58	0.01	0.01	17.9
c	2.2	5.6	1.0	0.56	0.02	0.01	18.4
x	2.1	5.7	1.0	0.57	0.02	0.01	18.2
17a	3.8	7.4	1.9	1.24	0.01	0.01	10.0
b	4.0	6.6	1.9	1.19	0.02	0.04	10.1
c	3.7	6.8	1.9	1.27	0.01	0.01	9.6
x	3.8	6.9	1.9	1.23	0.01	0.02	9.9

Depth	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
3a	0.08	0.03	0.08	0.06
b	0.07	0.06	0.02	0.02
c	0.07	--	0.02	--
x	0.07	0.04	0.04	0.04
11a	0.34	0.10	0.75	0.06
b	0.25	0.09	0.62	0.06
c	0.32	0.07	0.79	0.10
x	0.30	0.09	0.72	0.07
17a	2.12	0.23	1.85	0.63
b	1.84	0.14	1.79	0.39
c	1.63	0.13	1.65	0.44
x	1.86	0.17	1.76	0.49

(Continued)

Table B22 (Concluded)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ

Day 9 (August 20, 1988)

Depth m	BOD mg/ℓ	TOC mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	NO_3-N mg/ℓ	NO_2-N mg/ℓ	SO_4= mg/ℓ
3a	2.1	6.6	0.5	0.12	0.01	0.00	22.1
b	2.0	8.8	0.5	0.11	0.00	0.00	21.6
c	2.2	8.2	0.7	0.12	0.00	0.00	21.5
x	2.1	--	0.6	0.12	0.00	0.00	21.7
11a	2.6	6.7	1.1	0.53	0.02	0.00	18.9
b	2.6	6.8	1.0	0.52	0.02	0.00	19.4
c	2.6	8.6	1.0	0.53	0.01	0.00	18.6
x	2.6	7.4	1.0	0.53	0.02	0.00	19.0
17a	4.4	11.4	1.9	1.18	0.01	0.01	10.6
b	4.2	8.5	1.9	1.17	0.01	0.01	10.9
c	4.2	8.3	1.9	1.18	0.02	0.01	10.7
x	4.3	9.4	1.9	1.18	0.01	0.01	10.7

	Total Fe mg/ℓ	Dissolved Fe mg/ℓ	Total Mn mg/ℓ	Dissolved Mn mg/ℓ
3a	0.03	--	0.03	0.02
b	0.04	0.04	0.03	0.01
c	0.03	0.04	0.04	0.00
x	0.03	0.04	0.03	0.01
11a	0.20	0.05	0.45	0.05
b	0.19	0.03	0.43	0.05
c	0.17	0.03	0.42	0.05
x	0.19	0.04	0.43	0.05
17a	1.62	0.09	1.31	0.44
b	1.64	0.10	1.15	0.35
c	1.58	0.06	1.12	0.34
x	1.61	0.08	1.19	0.38

(Sheet 5 of 5)

Table B23

Canyon Reservoir Profile*

Depth m	Temperature °C	DO mg/ℓ
May 25, 1988		
1	24.4	8.7
2	24.3	8.4
3	24.2	8.4
4	24.1	8.4
5	24.1	8.4
6	23.6	8.3
7	23.2	8.2
8	23.1	8.3
9	22.0	8.3
10	21.2	7.3
11	20.7	7.1
12	18.4	6.5
13	16.5	6.4
14	16.2	6.3
15	15.8	6.3
16	15.5	6.2
17	15.2	6.1
18	14.6	6.0
19	14.5	6.0
20	14.1	5.9
21	14.0	6.2
22	13.7	6.2
23	13.5	6.1
24	13.4	6.1
25	13.2	6.3
26	13.1	6.5
27	13.0	6.4
28	12.9	6.3
29	12.8	6.4
30	12.7	6.1
31	12.5	5.9
32	12.5	5.6
33	12.4	5.5
34	12.4	5.1
35	12.2	5.1
36	12.2	5.1
37	12.2	5.0
38	12.2	4.9
39	12.2	5.0
40	12.2	4.9
41	12.2	5.1
(Continued)		

* Data furnished by Ben Hannan, Southwest Texas State University.

(Sheet 1 of 6)

Depth m	Temperature °C	DO mg/ℓ

June 11, 1988

Depth m	Temperature °C	DO mg/ℓ
1	25.5	8.2
2	25.6	8.3
3	25.5	8.4
4	25.4	8.4
5	25.3	8.5
6	25.2	8.6
7	25.2	8.6
8	24.3	7.9
9	24.1	7.5
10	23.9	7.3
11	23.6	6.9
12	21.2	4.9
13	20.0	4.6
14	18.0	4.6
15	17.2	4.9
16	16.1	5.0
17	15.9	5.2
18	15.4	5.2
19	15.3	5.2
20	14.9	5.2
21	14.6	5.5
22	14.4	5.5
23	14.3	5.5
24	14.1	5.4
25	14.0	5.3
26	13.7	5.3
27	13.6	5.0
28	13.3	5.0
29	13.2	4.9
30	13.1	4.9
31	13.0	4.7
32	12.9	4.3
33	12.8	4.2
34	12.8	4.1
35	12.8	4.2
36	12.7	4.0
37	12.6	3.7
38	12.5	3.6
39	12.4	3.7
40	12.3	3.4
41	12.3	3.0

(Continued)

(Sheet 2 of 6)

Depth m	Temperature °C	DO mg/ℓ

June 25, 1988

Depth m	Temperature °C	DO mg/ℓ
1	27.4	8.4
2	27.4	8.3
3	27.4	8.3
4	27.3	8.3
5	27.2	8.3
6	27.2	8.4
7	26.2	8.3
8	25.3	7.4
9	24.8	6.0
10	24.3	5.6
11	23.0	4.8
12	21.0	3.9
13	20.1	3.8
14	19.8	3.8
15	18.3	3.7
16	17.6	4.0
17	16.6	4.1
18	16.1	4.4
19	15.8	4.4
20	15.6	4.5
21	15.1	4.6
22	15.0	4.6
23	14.6	4.7
24	14.5	4.6
25	14.3	4.5
26	14.1	4.4
27	13.9	4.5
28	13.8	4.5
29	13.5	4.2
30	13.3	3.9
31	13.3	3.6
32	13.2	3.5
33	13.1	3.4
34	13.1	3.3
35	13.1	3.1
36	13.0	3.0
37	12.8	2.9
38	12.7	2.4
39	12.6	2.3
40	12.6	2.2

(Continued)

(Sheet 3 of 6)

Depth m	Temperature °C	DO mg/ℓ

<u>July 27, 1988</u>

Depth m	Temperature °C	DO mg/ℓ
0	29.1	8.8
1	29.1	8.9
2	29.0	8.8
3	28.7	8.8
4	28.9	8.8
5	28.7	8.8
6	28.4	8.7
7	28.2	8.6
8	28.0	7.1
9	27.2	5.1
10	26.2	2.3
11	25.5	1.4
12	25.0	0.9
13	24.0	0.8
14	23.1	1.0
15	22.2	1.0
16	20.8	0.9
17	19.5	0.9
18	18.5	1.6
19	17.5	1.8
20	17.2	2.5
21	16.8	2.7
22	16.2	2.9
23	16.1	3.0
24	15.7	2.9
25	15.5	2.6
26	15.0	2.4
27	14.9	2.1
28	14.7	1.8
29	14.6	2.1
30	14.4	2.3
31	14.3	2.0
32	14.2	1.6
33	14.1	2.0
34	14.0	1.8
35	13.9	1.2
36	13.8	1.1
37	13.6	1.0
38	13.4	0.8
39	13.3	0.6
40	13.0	0.4
41	13.1	0.1
42	13.0	0.0

(Continued)

Depth m	Temperature °C	DO mg/ℓ	Cond. μsec

August 18, 1988

Depth m	Temperature °C	DO mg/ℓ	Cond. μsec
1	29.9	8.5	323
2	29.9	8.4	323
3	29.9	8.4	323
4	29.9	8.4	323
5	29.9	8.4	323
6	29.8	8.4	323
7	29.3	8.4	323
8	29.0	6.9	325
9	27.9	2.9	338
10	27.4	1.0	341
11	27.0	0.1	379
12	25.8	0.0	385
13	25.7	0.0	337
14	24.8	0.0	340
15	23.5	0.0	363
16	22.8	0.0	376
17	22.0	0.0	387
18	21.1	0.0	394
19	20.5	0.0	396
20	19.5	0.0	398
21	19.4	0.0	400
22	18.5	0.0	405
23	17.9	0.0	403
24	17.5	1.0	406
25	16.8	0.6	406
26	16.2	0.3	408
27	15.8	0.1	408
28	15.5	0.1	408
29	15.2	0.2	407
30	15.0	0.0	408
31	14.8	0.0	407
32	14.7	0.0	408
33	14.6	0.0	407
34	14.5	0.0	407
35	14.4	0.0	406
36	14.3	0.0	407
37	14.0	0.0	407
38	13.8	0.0	407
39	13.5	0.0	407
40	13.4	0.0	406
41	13.4	0.0	406
42	13.4	0.0	406

(Continued)

(Sheet 5 of 6)

Depth m	Temperature °C	DO mg/ℓ	pH	Cond. μsec

September 21, 1988

Depth m	Temperature °C	DO mg/ℓ	pH	Cond. μsec
0	27.0	7.4	7.9	362
1	27.0	7.2	7.8	362
2	27.0	7.1	7.8	362
3	27.0	7.0	7.8	362
4	27.0	7.1	7.8	362
5	26.9	7.0	7.8	362
6	26.8	6.9	7.8	362
7	26.8	6.8	7.9	362
8	26.7	6.8	7.9	362
9	26.7	6.3	7.8	363
10	26.6	6.1	7.8	363
11	26.6	6.0	7.8	363
12	26.6	6.0	7.8	363
13	26.0	2.3	7.7	369
14	25.7	0.6	7.6	370
15	25.3	0.4	7.5	372
16	24.1	0.3	7.4	373
17	23.0	0.0	7.4	396
18	22.2	0.2	7.4	405
19	21.7	0.2	7.3	410
20	20.9	0.2	7.2	418
21	20.0	0.2	7.1	423
22	19.1	0.2	7.1	428
23	18.7	0.1	7.0	430
24	18.0	0.1	6.9	433
25	17.4	0.1	6.8	434
26	17.2	0.1	6.8	435
27	16.7	0.1	6.8	435
28	16.5	0.1	6.8	435
29	16.3	0.1	6.8	436
30	16.0	0.1	6.8	436
31	15.8	0.0	6.7	436
32	15.8	0.1	6.7	436
34	15.6	0.0	--	436
36	15.4	0.0	--	436
38	15.0	0.0	--	436

(Sheet 6 of 6)

Table B24

Canyon Reservoir Lake Sampling*

Depth m	Total Fe µg/ℓ	Dissolved Fe µg/ℓ	Total Mn µg/ℓ	Dissolved Mn µg/ℓ
		September 21, 1988		
3	43	55	8	5
10	49	31	9	5
15	86	73	34·	12
25	99	24	13	14
30	212	26	71	65
34	235	85	124	122
36	246	27	148	123
38	230	44	151	139

* Pool elevation at 277.15 m.

Table B25

Canyon Reservoir Tailwater Sampling

Station	Temperature °C	DO mg/ℓ	pH	SC μsec	NH_3-N mg/ℓ	NO_3-N mg/ℓ

September 19, 1988

Station	Temperature °C	DO mg/ℓ	pH	SC μsec	NH_3-N mg/ℓ	NO_3-N mg/ℓ
A	17.2	8.8	7.5	445	0.11	0.04
B	17.7	8.4	7.7	446	0.10	0.05
C	19.1	8.6	7.8	446	0.08	0.07
D	20.6	8.2	7.8	461	0.06	0.13
E	22.5	8.1	7.9	444	0.03	0.10
F	23.1	8.0	7.9	440	0.03	0.10

	Cl- mg/ℓ	SO_4= mg/ℓ	Total Fe μg/ℓ	Dissolved Fe μg/ℓ	Total Mn μg/ℓ	Dissolved Mn μg/ℓ
A	15.8	15.3	165	12	172	168
B	15.5	15.4	196	2	136	127
C	15.5	16.4	191	0	93	36
D	15.4	17.4	111	0	50	33
E	15.7	16.1	35	0	19	10
F	14.8	15.0	285	7	70	14

APPENDIX C: GRAPHICAL WATER QUALITY DATA FOR INPOOL AND TAILWATER STATIONS

March 25, 1987

April 15, 1987

May 11, 1987

June 8, 1987

July 7, 1987

September 3, 1987

October 12, 1987

November 3, 1987
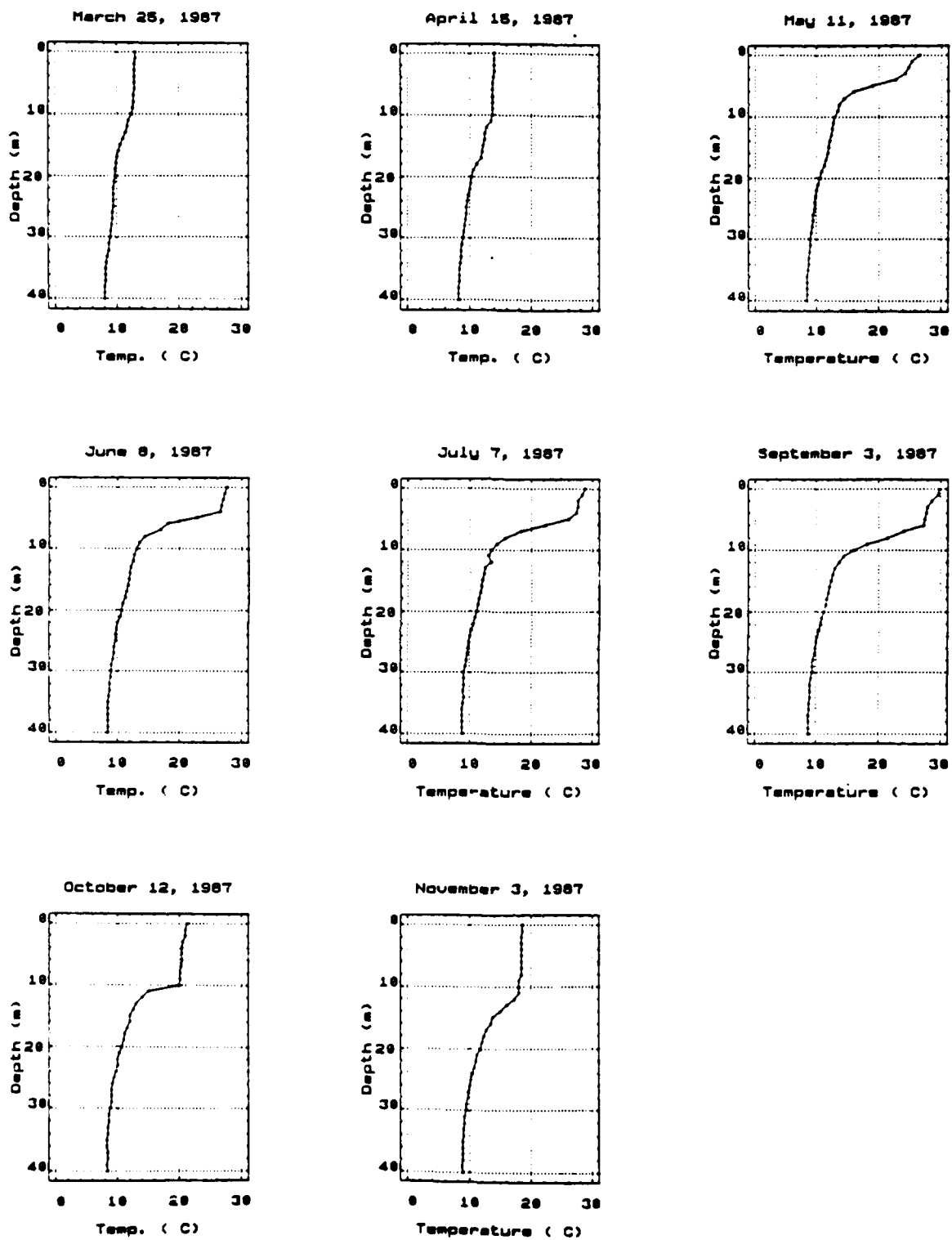
Figure C1.   Lake Greeson (station G1) temperature profiles
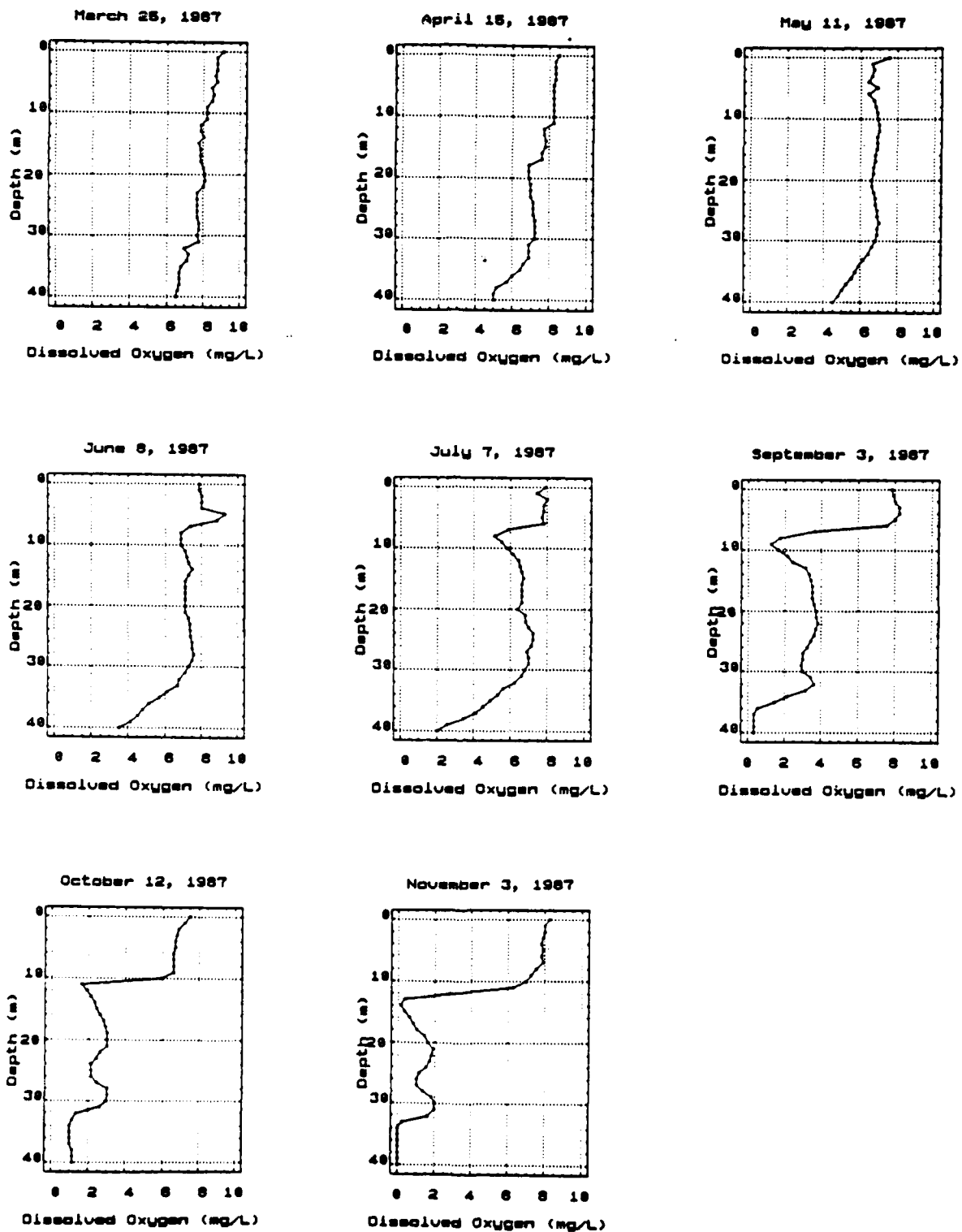
Figure C2. Lake Greeson (station G1) DO profiles
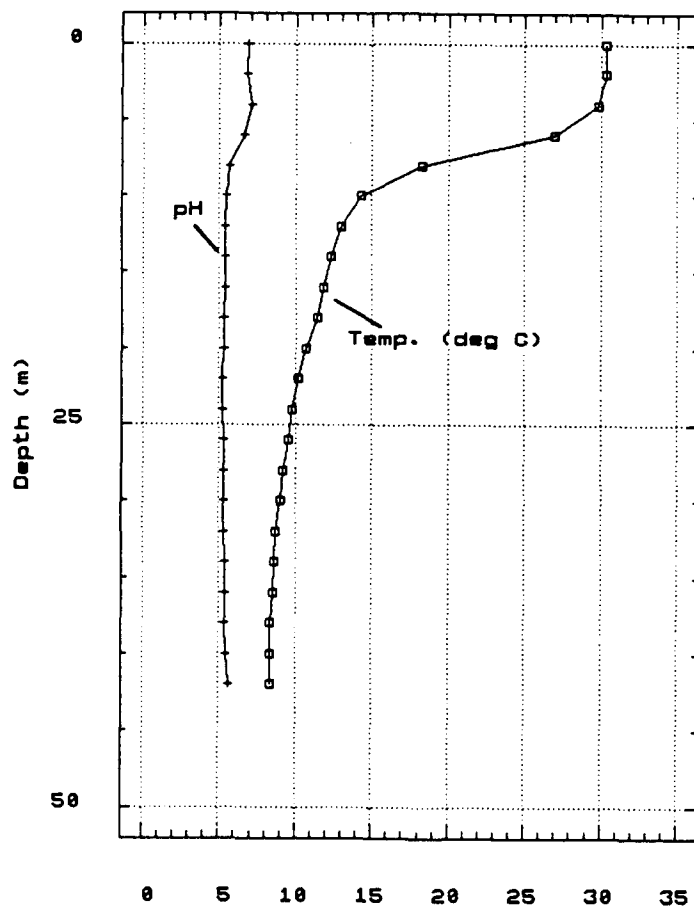
Figure C3. Lake Greeson (station G1) temperature and pH profile on 7/28/87

Lake Greeson
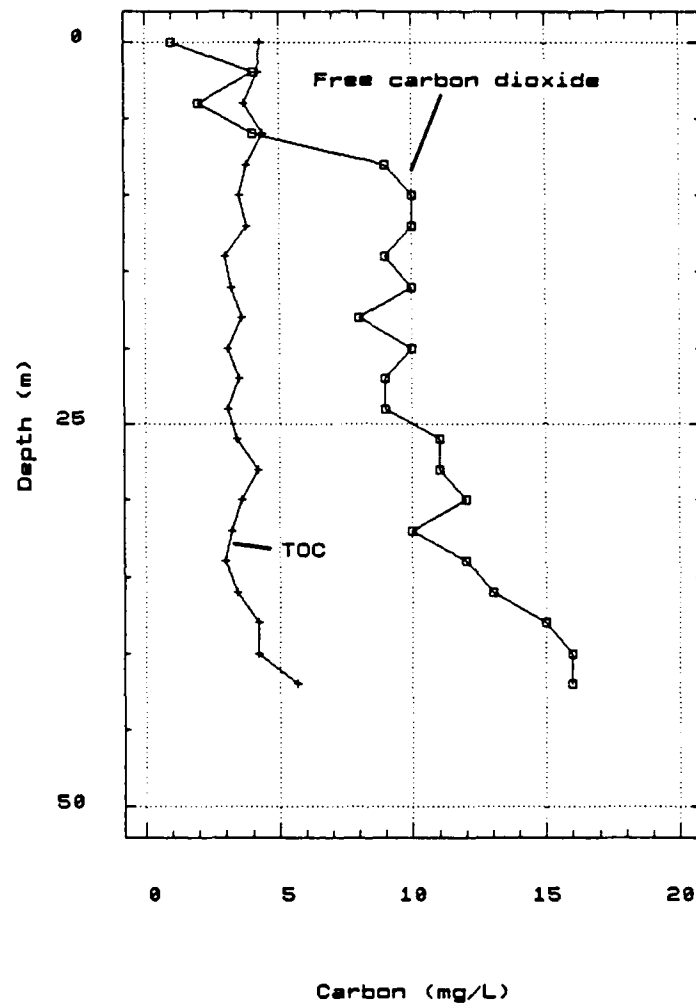
7/28/87

Figure C4. Lake Greeson (station G1) total organic carbon and free CO_2 profile on 7/28/87
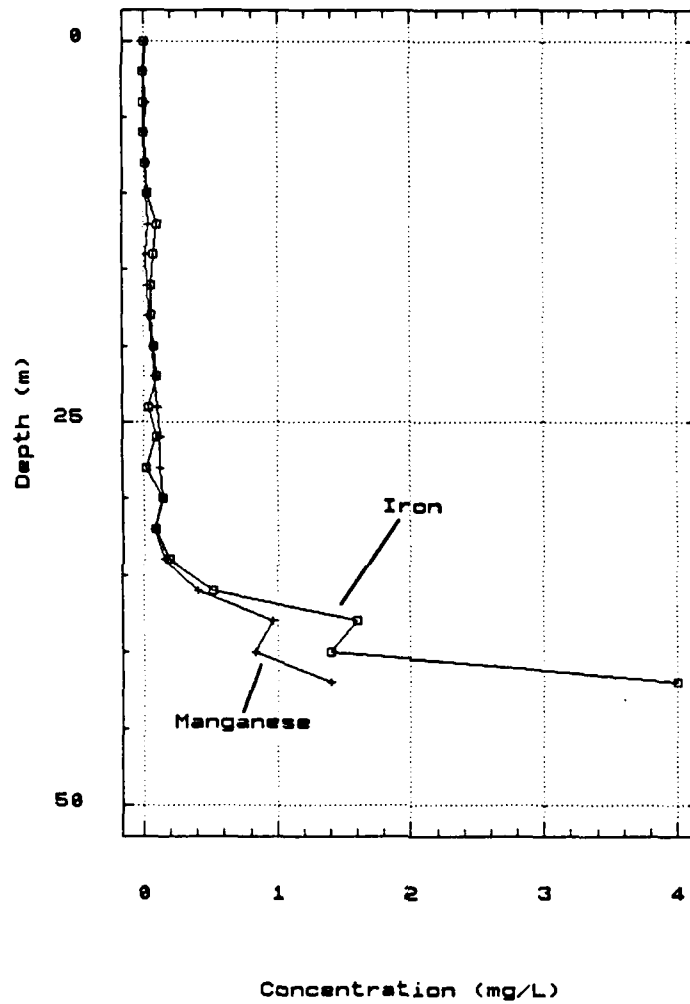
Figure C5. Lake Greeson (station G1) Mn and Fe profile on 7/28/87

Lake Greeson
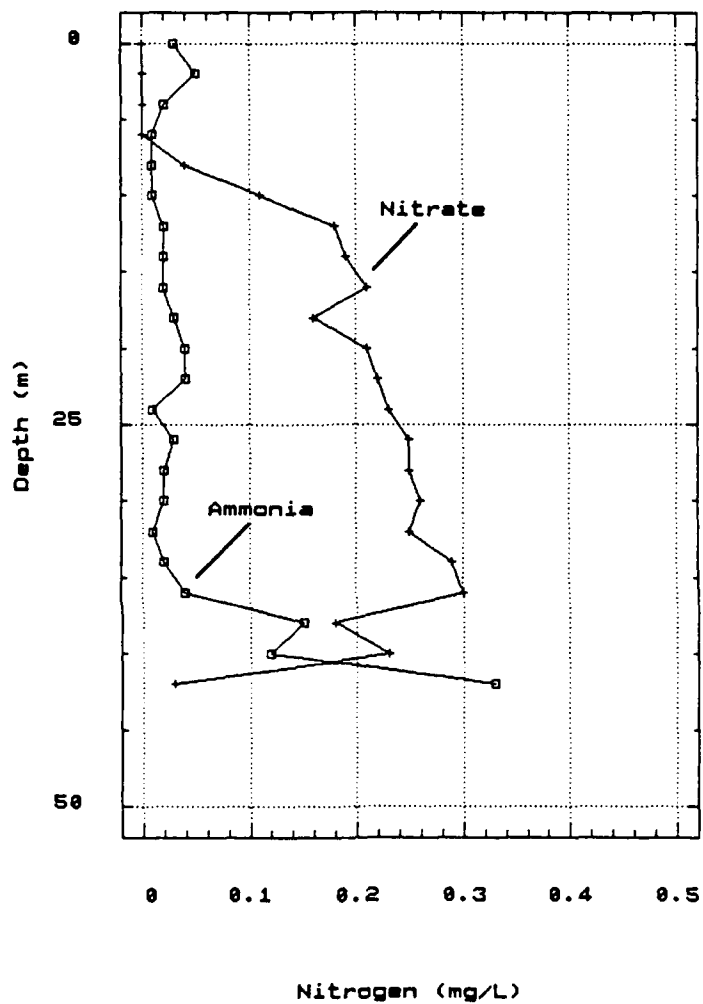
7/28/87

Figure C6. Lake Greeson (station G1) ammonia nitrogen and nitrate nitrogen profile for 7/28/87

Greeson Tailwater (Sta.B)
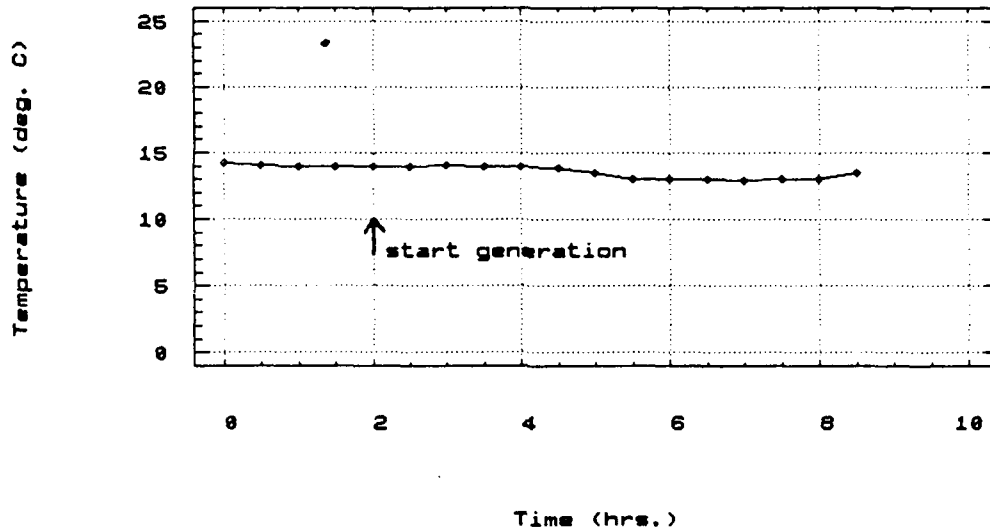
7/28/87

Figure C7.   Greeson tailwater (station B)
temperature versus time on 7/28/87

Greeson Tailwater (Sta.B)
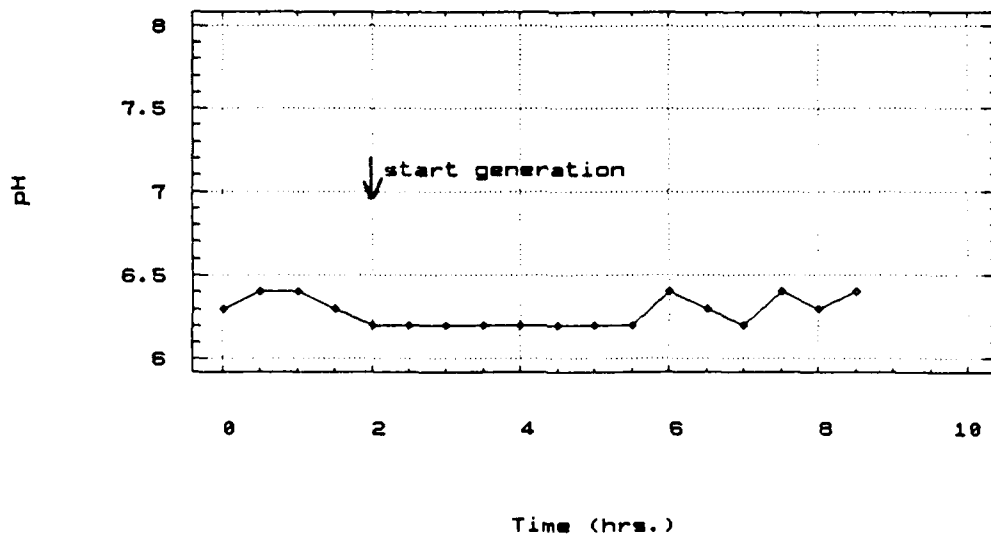
7/28/87

Figure C8.   Greeson tailwater (station B)
pH versus time on 7/28/87
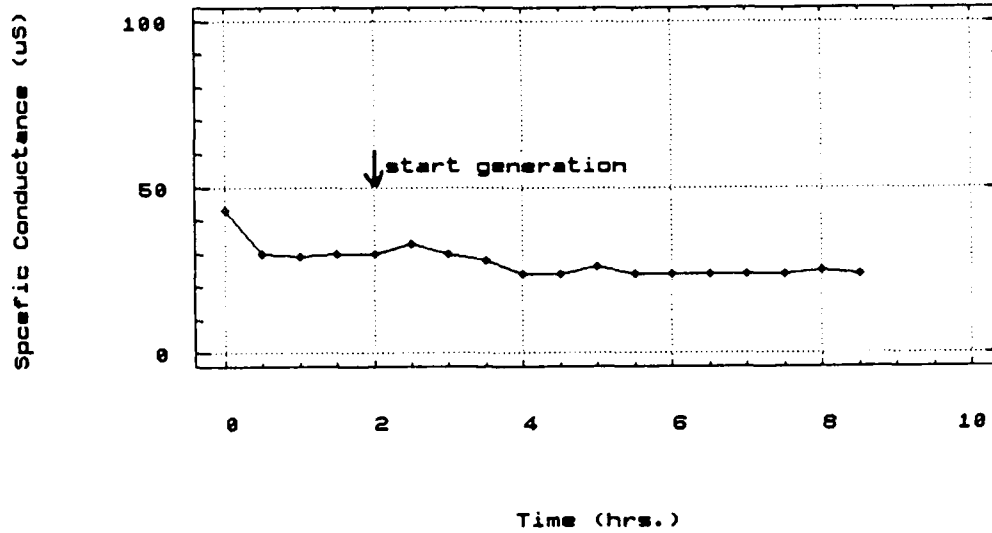
7/28/87

Figure C9. Greeson tailwater (station B)
specific conductance versus time on
7/28/87

Greeson Tailwater (Sta. B)
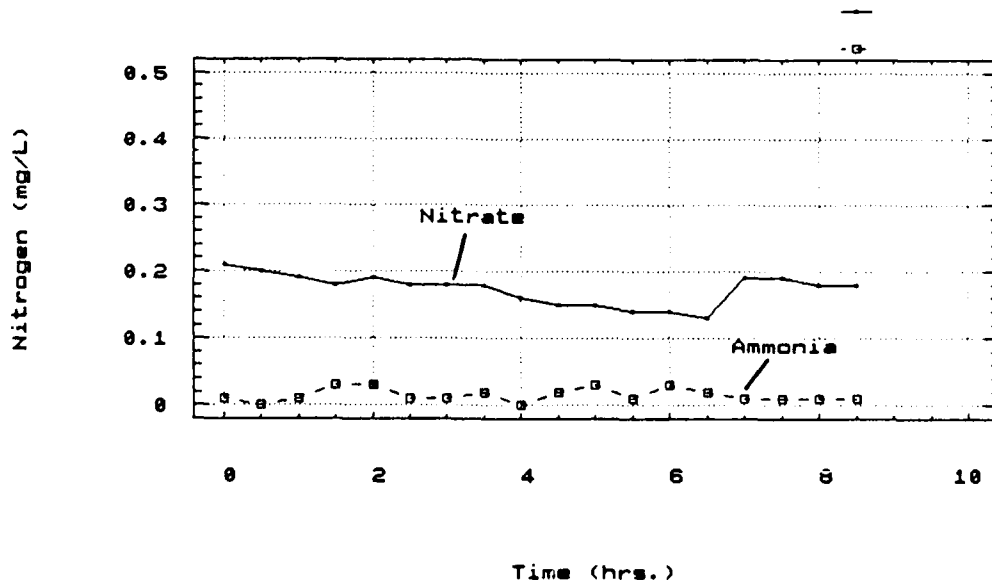
7/28/87

Figure C10. Greeson tailwater (station B)
ammonia nitrogen and nitrate nitrogen
versus time on 7/28/87
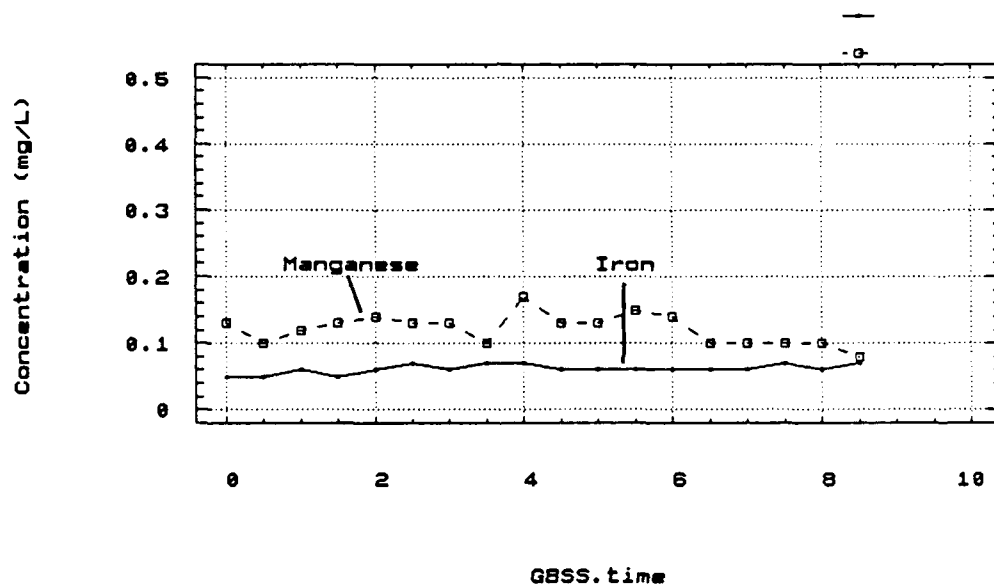
Figure C11. Greeson tailwater (station B)
manganese and iron versus time on 7/28/87
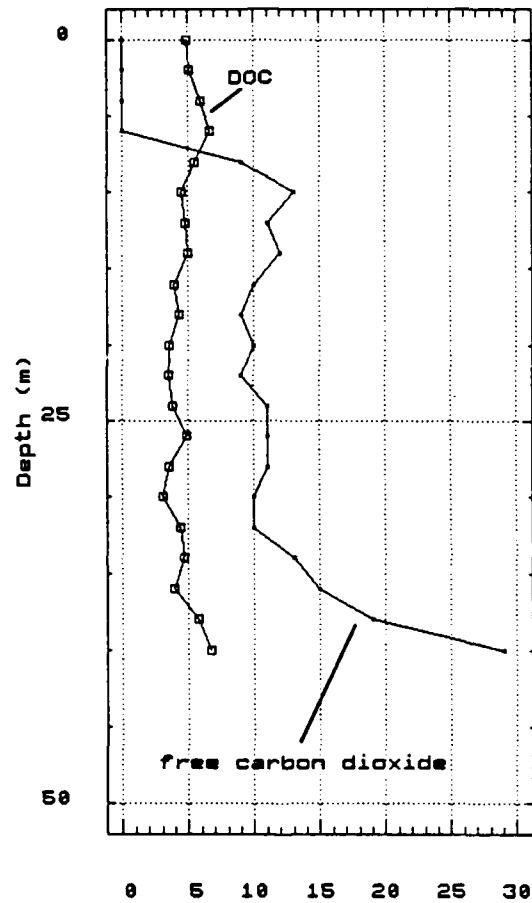
Figure C12. Lake Greeson (station G1) DOC and free CO_2 profile on 9/12/87

C12
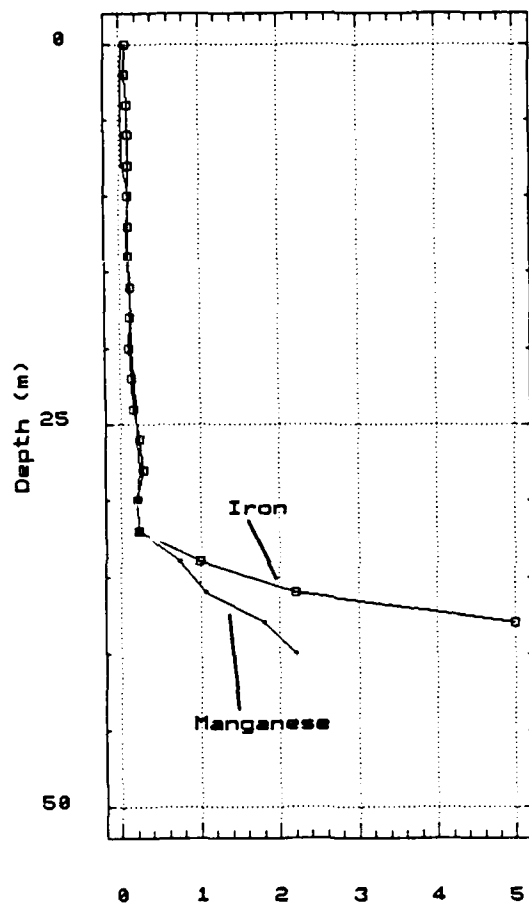
Lake Greeson

9/12/87

Figure C13. Lake Greeson (station G1) iron and manganese profile on 9/12/87

C13
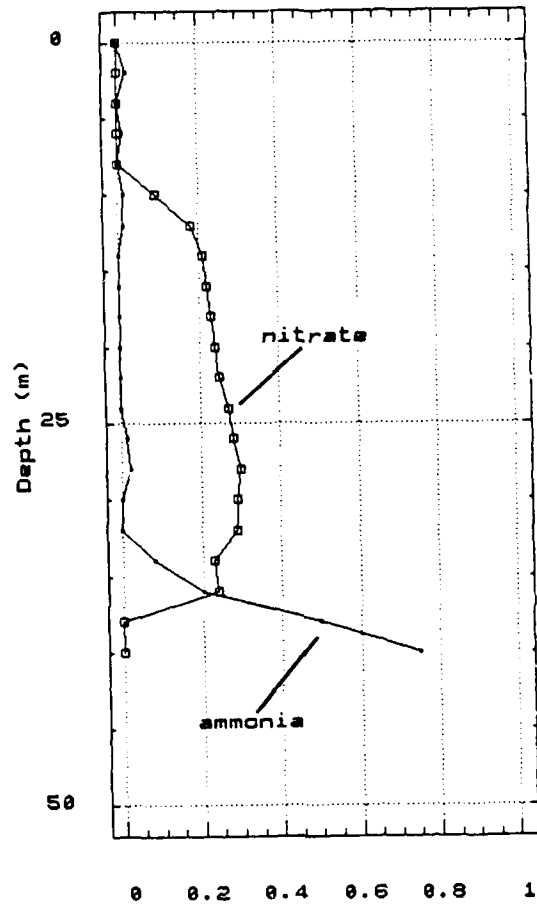
Lake Greeson

9/12/87

Nitrogen (mg/L)

Figure C14. Lake Greeson
(station G1) ammonia
nitrogen and nitrate
nitrogen profile on
9/12/87
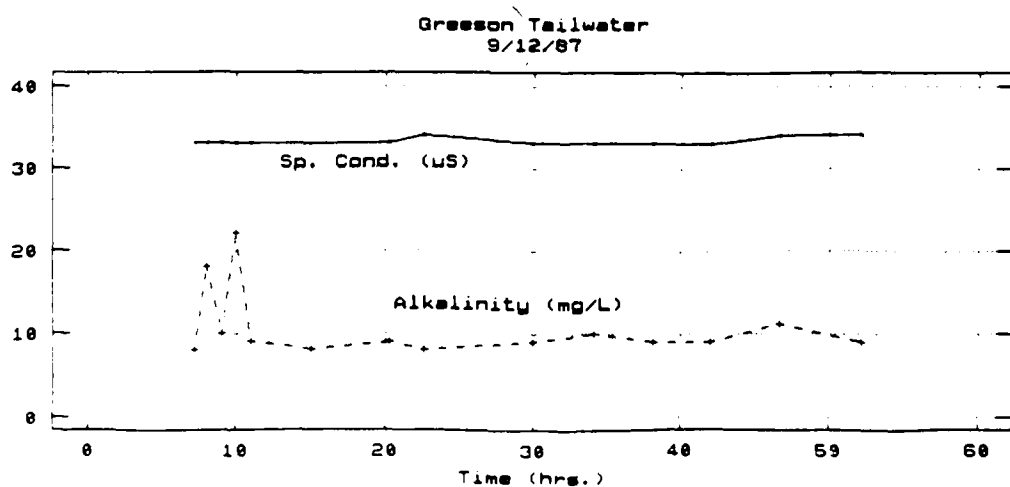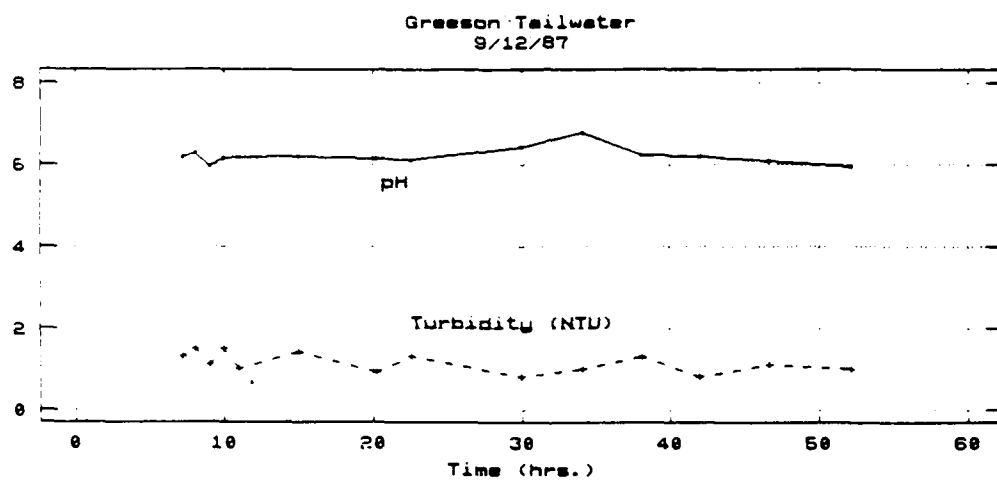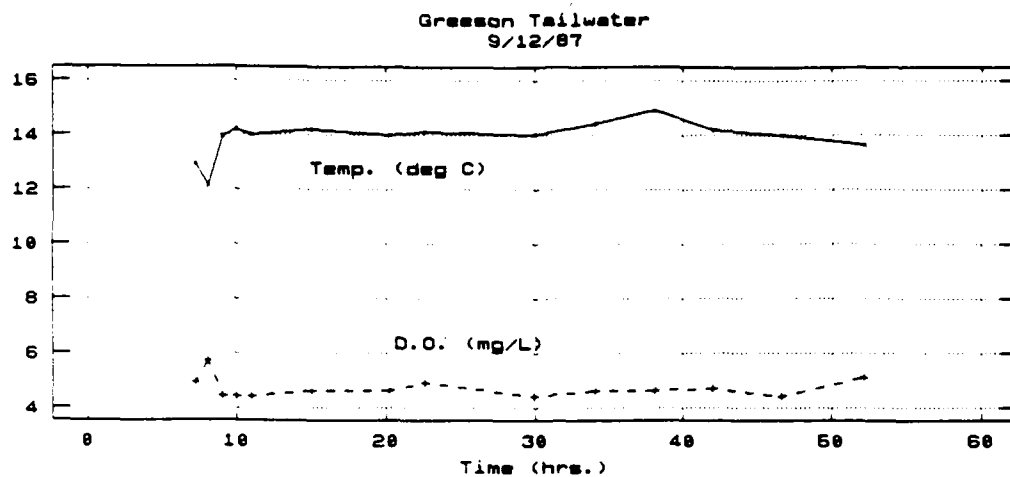
Figure C15. Greeson tailwater (station A) temperature,
DO, pH, turbidity, specific conductivity, and
alkalinity versus time beginning on 9/12/87

C15

Greeson Tailwater
9/12/87

Nitrate Nitrogen

total P

Time (hrs.)

Greeson Tailwater
9/12/87

total Iron (mg/L)

total manganese (mg/L)

Time (hrs.)

Greeson Tailwater
9/12/87

Sulfate (mg/L)

Chloride (mg/L)

Time (hrs.)
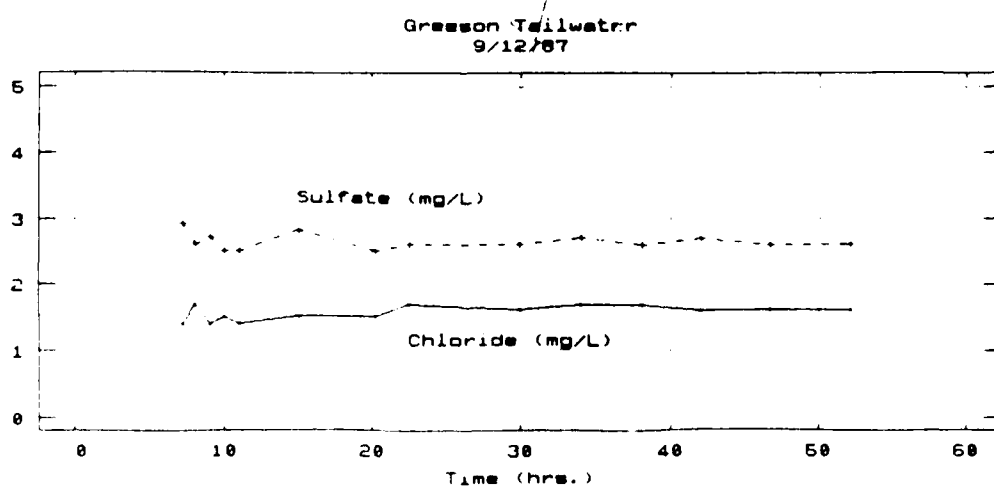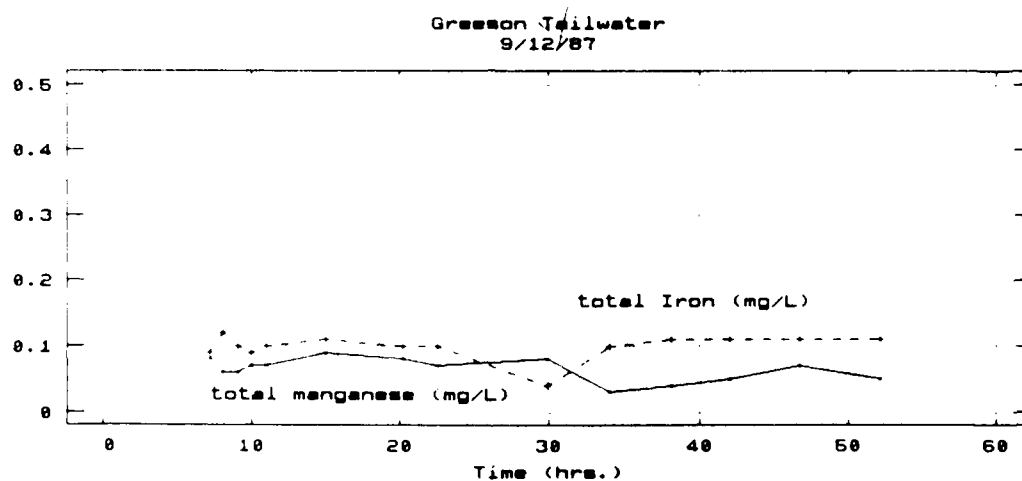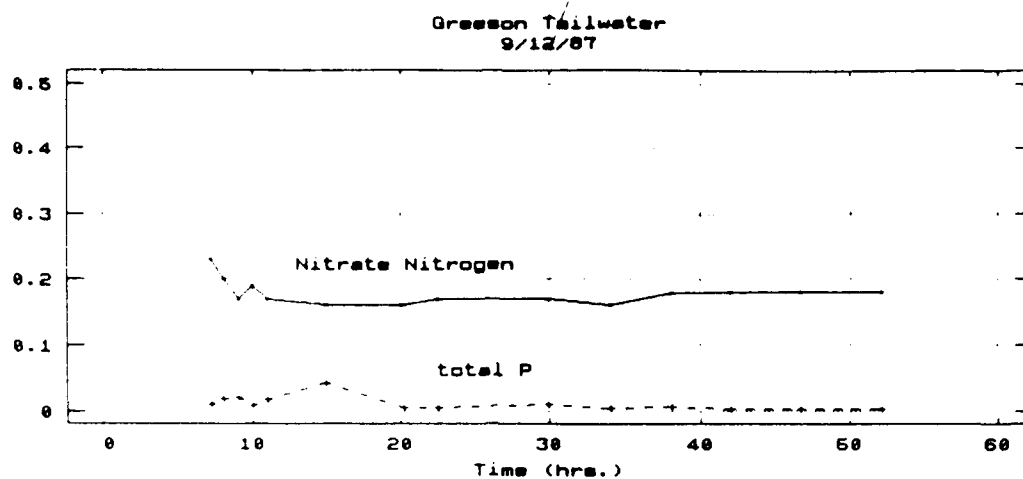
Figure C16. Greeson tailwater (station A) nitrate
nitrogen, total phosphorus, total iron, total
manganese, sulfate and chloride versus time
beginning on 9/12/87

C16

Lake Greeson

Station 1

Before generation

After generation

Temp. (deg C)
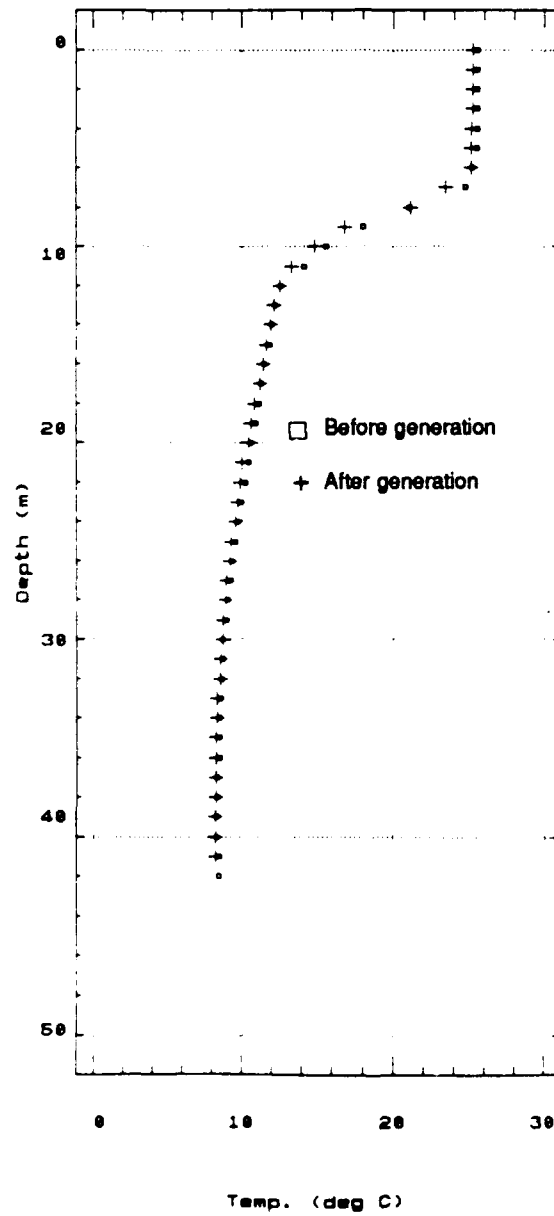
Figure C17. Lake Greeson
(station G-1) temperature
profile before and after
48-hr generation period,
9/12/87 and 9/14/87

Lake Greeson
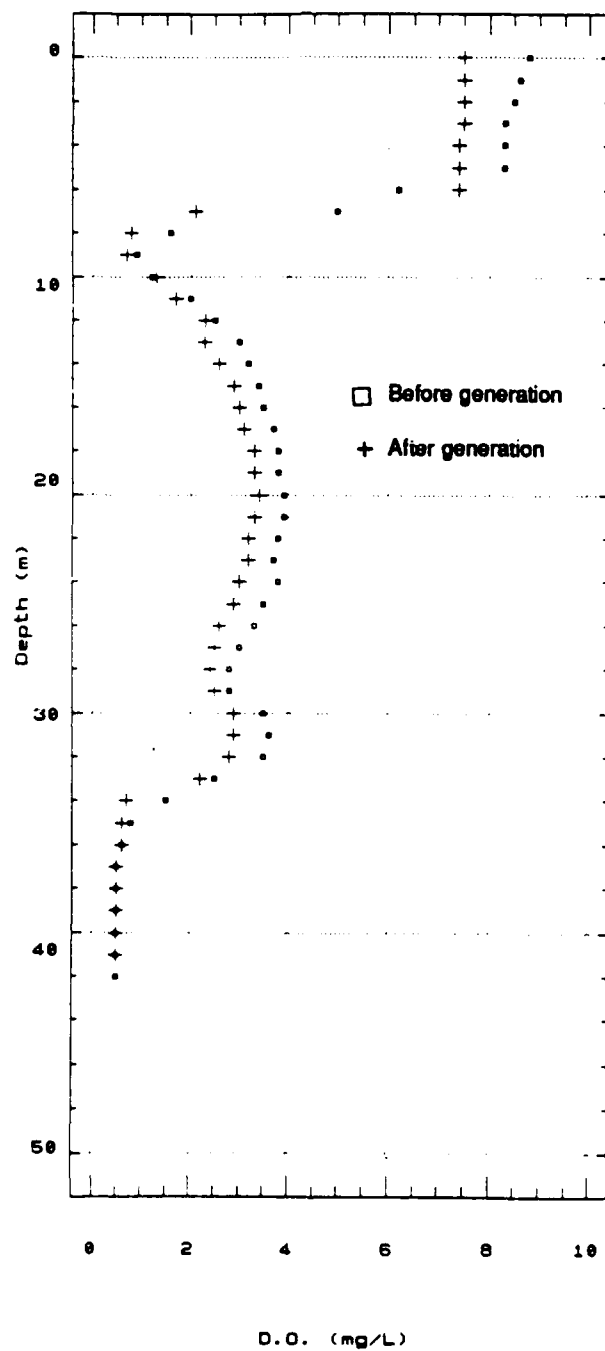
Station 1

Figure C18. Lake Greeson (station G-1) temperature profile before and after 48-hr generation period, 9/12/87 and 9/14/87

C18
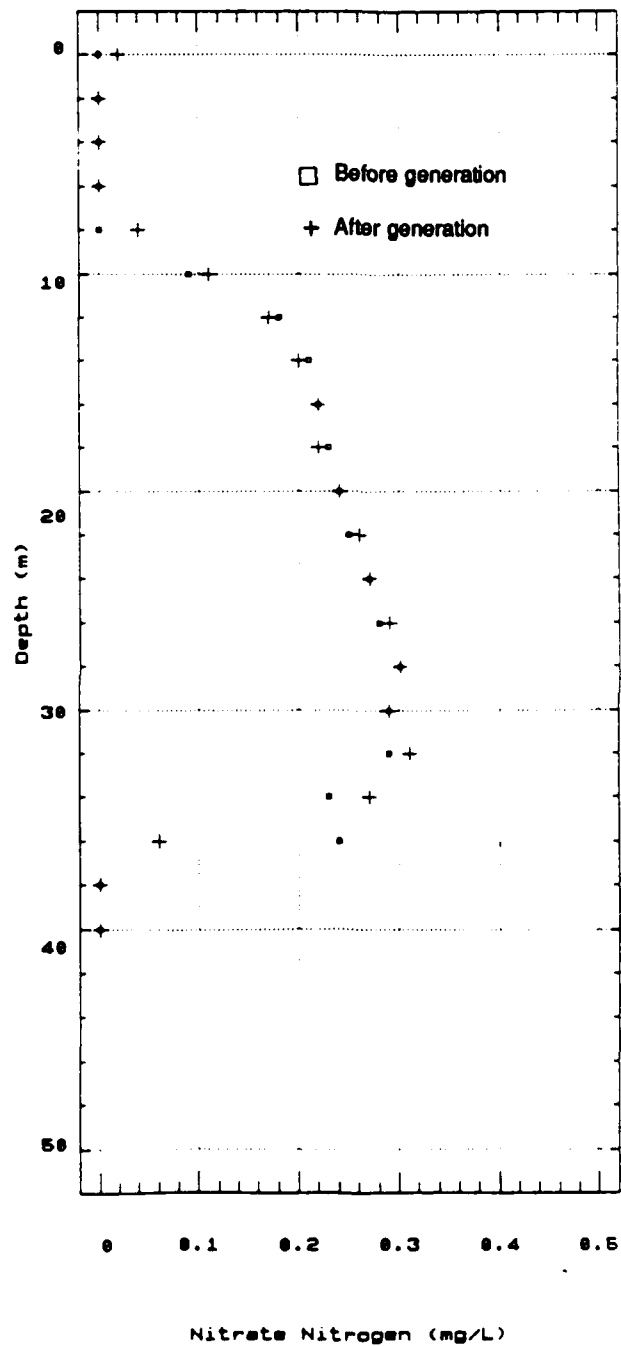
Figure C19. Lake Greeson
(station G-1) nitrate
nitrogen profile before
and after 48-hr generation
period, 9/12/87 and 9/14/87

C19

GREESON TAILWATER
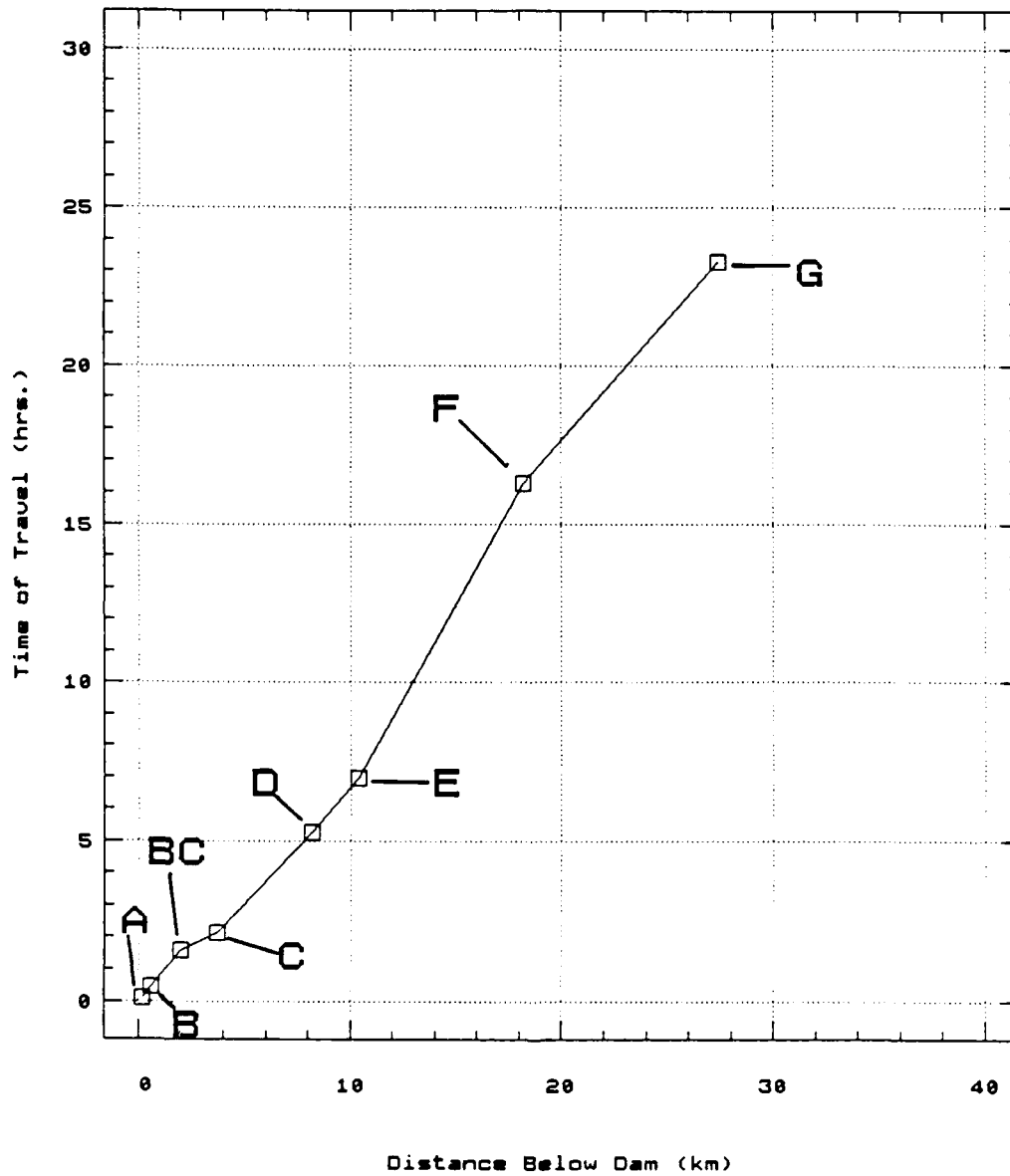
September 1987

Figure C20. Lake Greeson tailwater, estimated
time of travel versus distance to downstream
stations, 9/12/87-9/14/87

GREESON TAILWATER
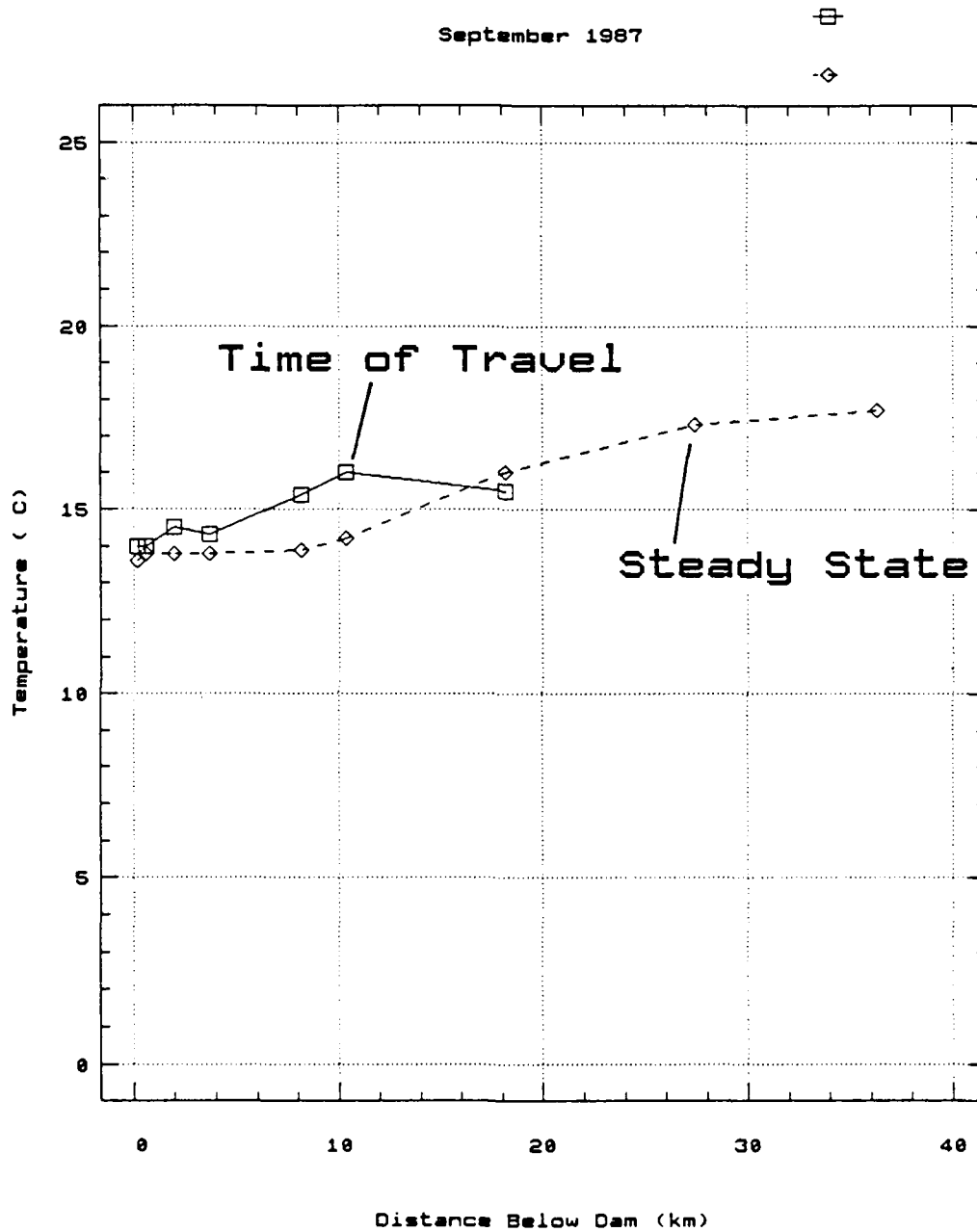
September 1987

Figure C21. Lake Greeson tailwater, temperature versus distance below dam for time-of-travel and steady-state sampling, 9/12/87-9/14/87

GREESON TAILWATER
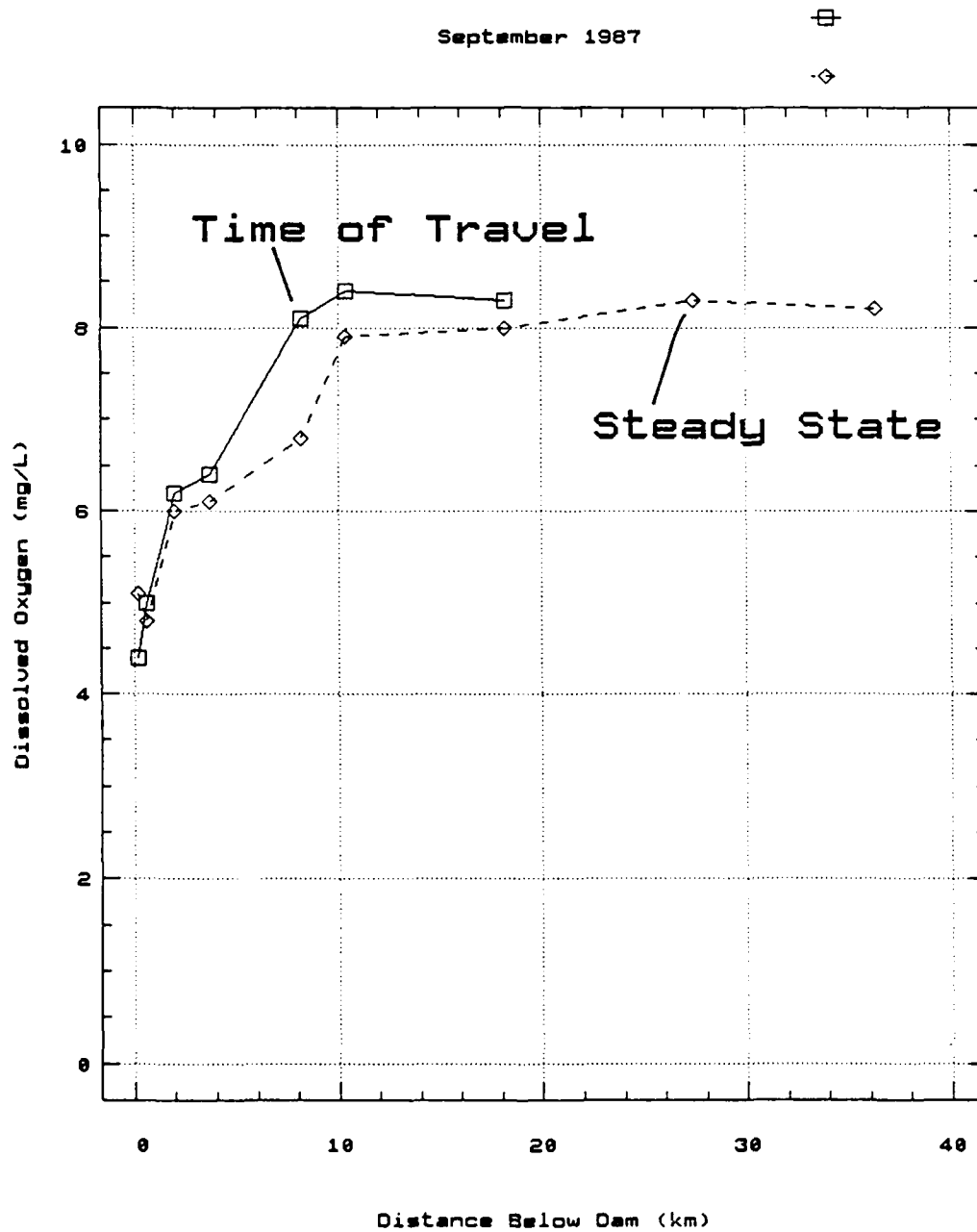
September 1987

Figure C22. Lake Greeson tailwater, DO
versus distance below dam for time-of-
travel and steady-state sampling,
9/12/87-9/14/87

GREESON TAILWATER
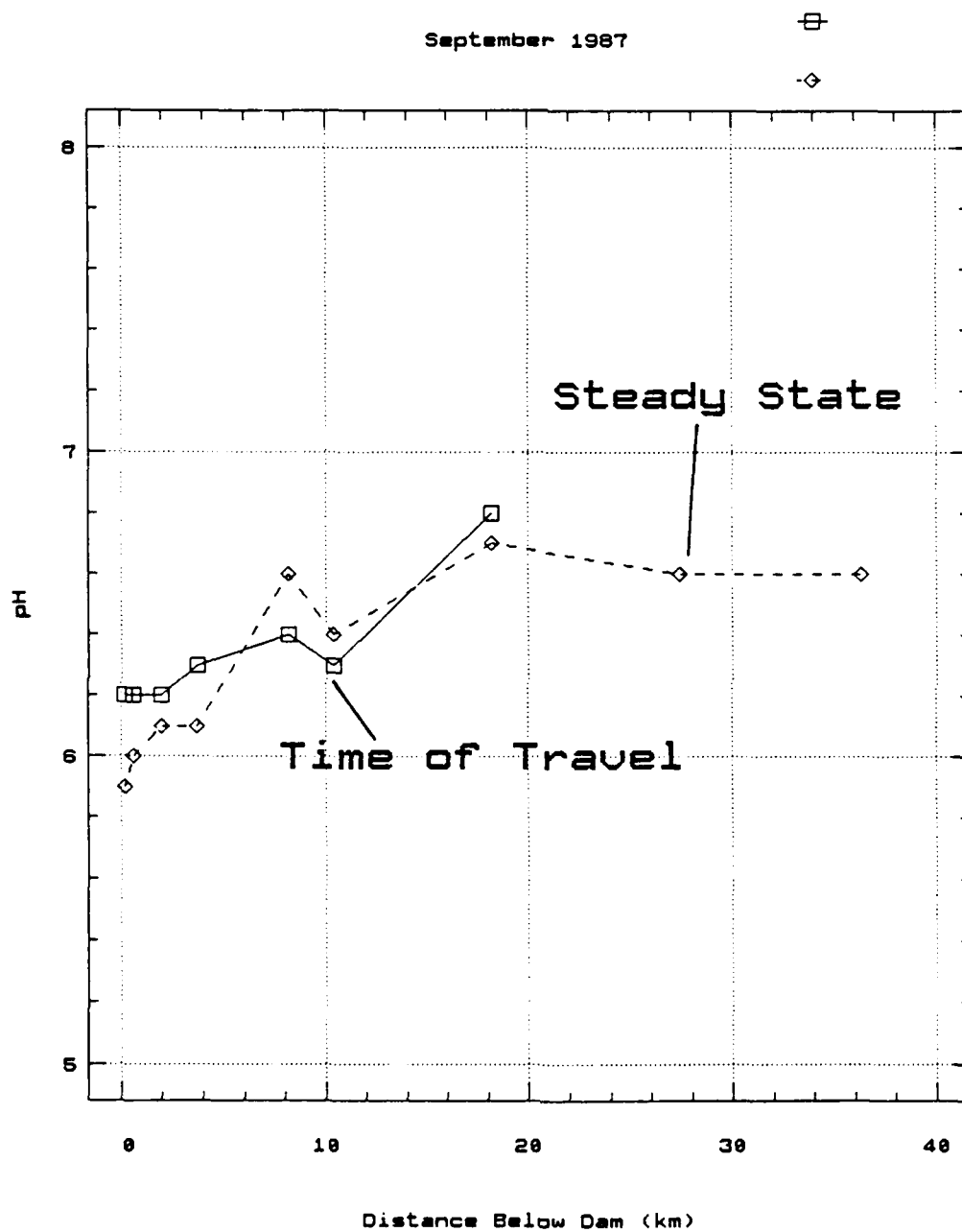
September 1987

Figure C23. Lake Greeson tailwater, pH
versus distance below dam for time-of-
travel and steady-state sampling,
9/12/87-9/14/87

C23

GREESON TAILWATER
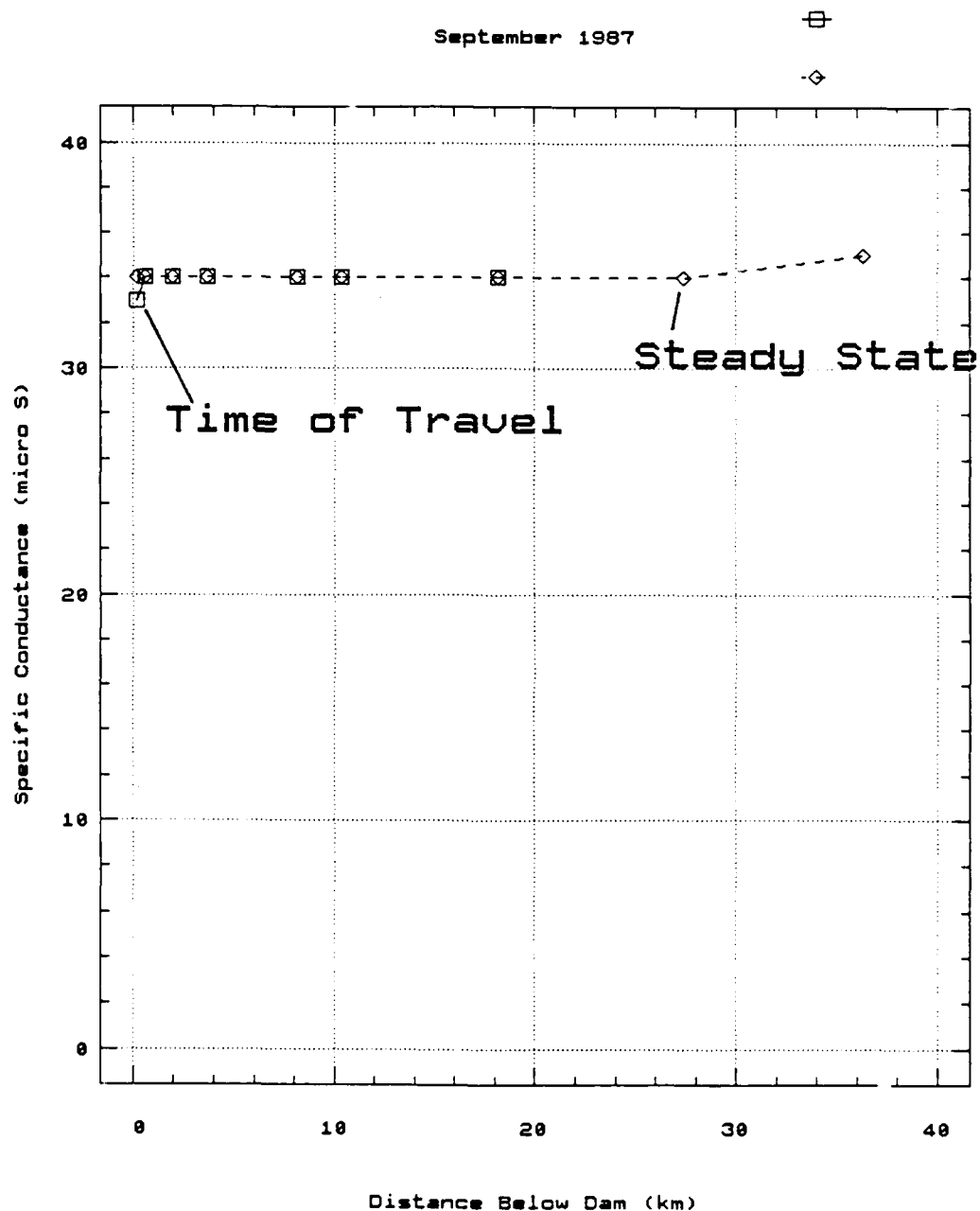
September 1987

Figure C24. Lake Greeson tailwater,
specific conductance versus distance
below dam for time-of-travel and
steady-state sampling, 9/12/87-
9/14/87

GREESON TAILWATER
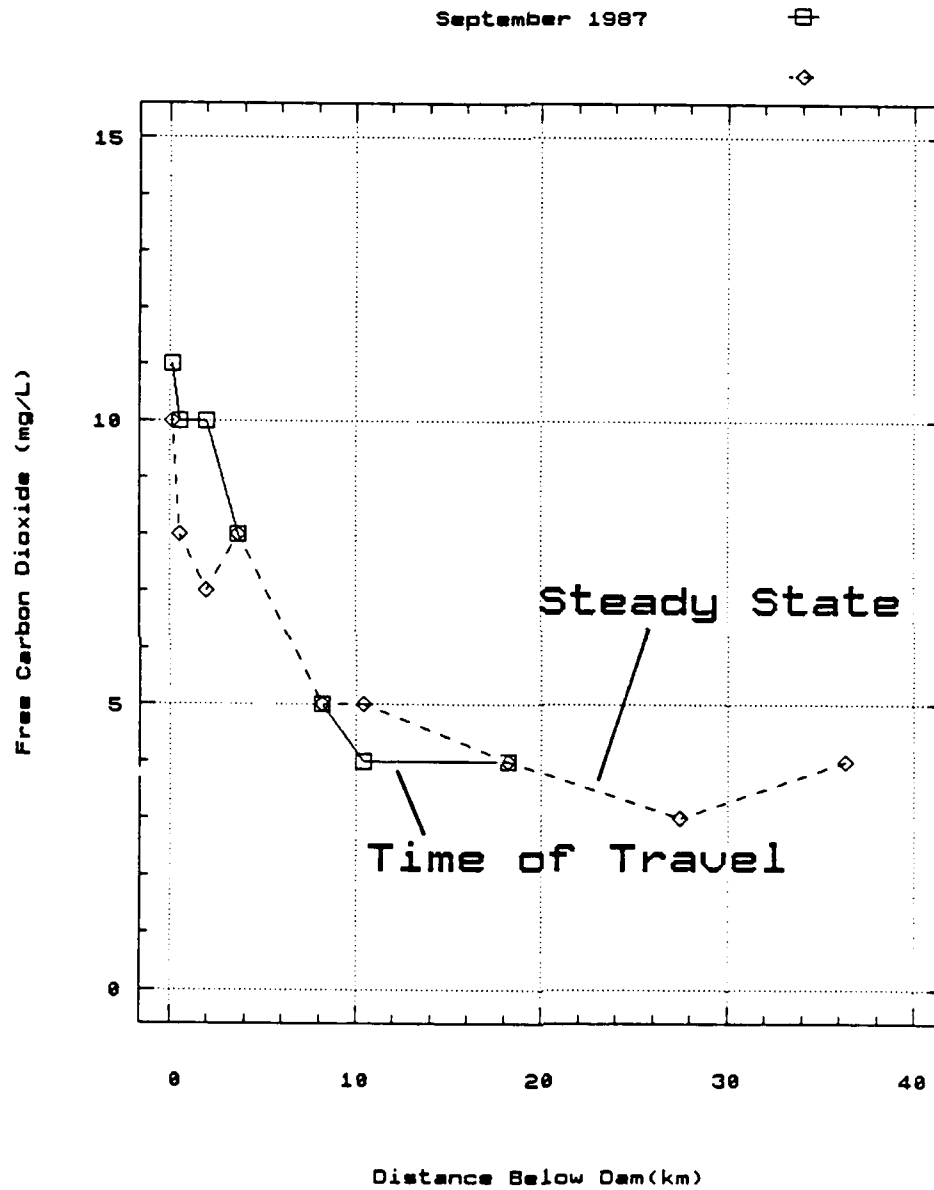
September 1987

Figure C25. Lake Greeson tailwater, free CO_2 versus distance below dam for time-of-travel and steady-state sampling, 9/12/87-9/14/87

GREESON TAILWATER
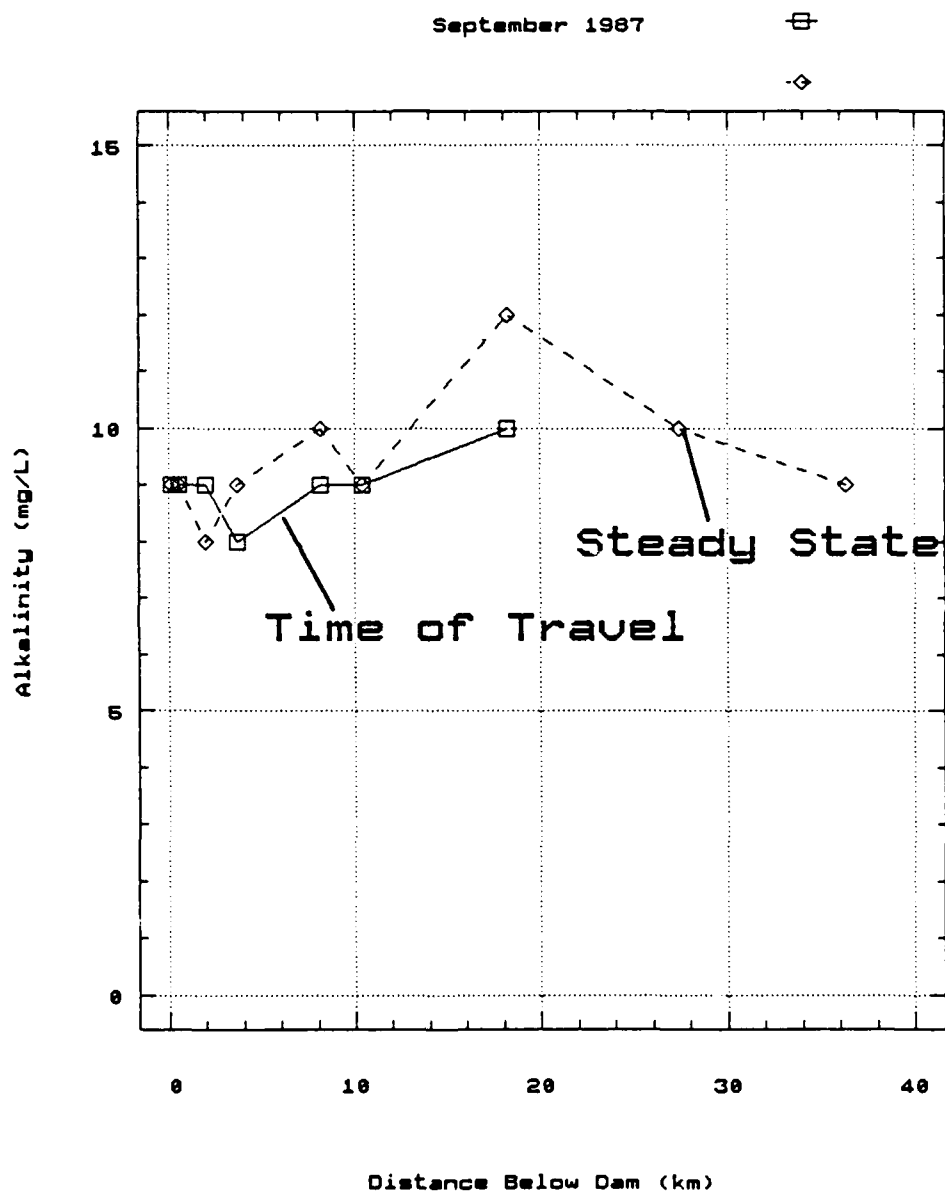
September 1987

Figure C26. Lake Greeson tailwater, alkalinity versus distance below dam for time-of-travel and steady-state sampling, 9/12/87-9/14/87

C26

GREESON TAILWATER
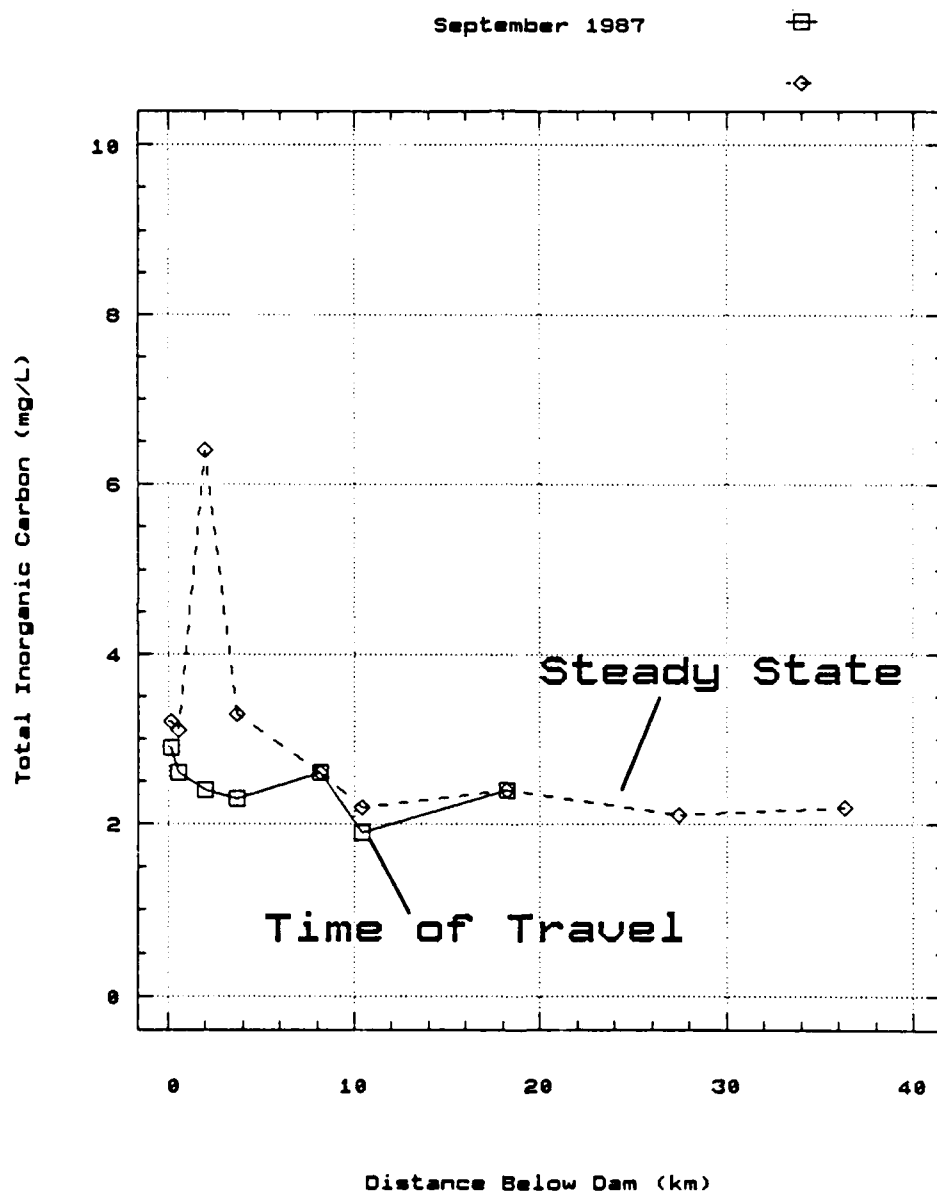
September 1987

Figure C27.   Lake Greeson tailwater, total
inorganic carbon versus distance below dam
for time-of-travel and steady-state
sampling, 9/12/87-9/14/87

GREESON TAILWATER
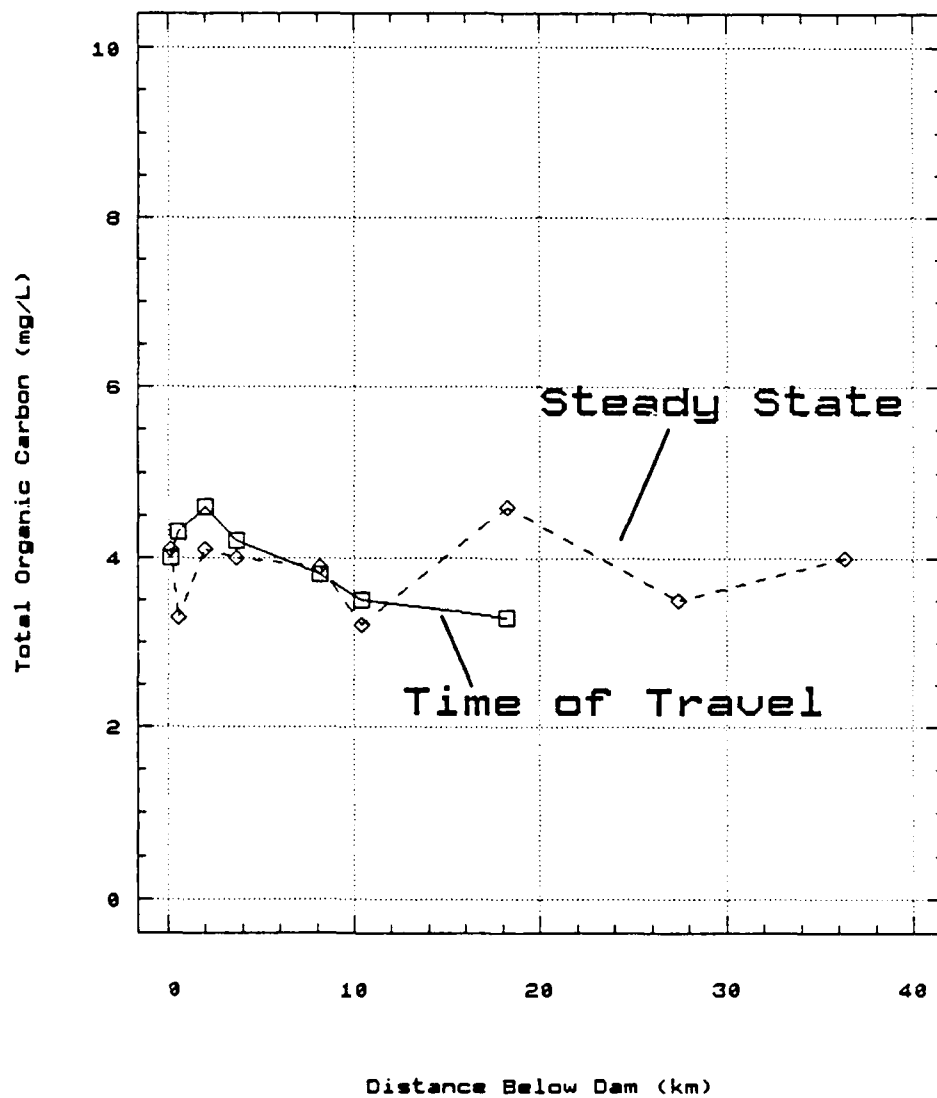
September 1987

Figure C.8. Lake Greeson tailwater, total
organic carbon versus distance below dam
for time-of-travel and steady-state
sampling, 9/12/87-9/14/87

GREESON TAILWATER
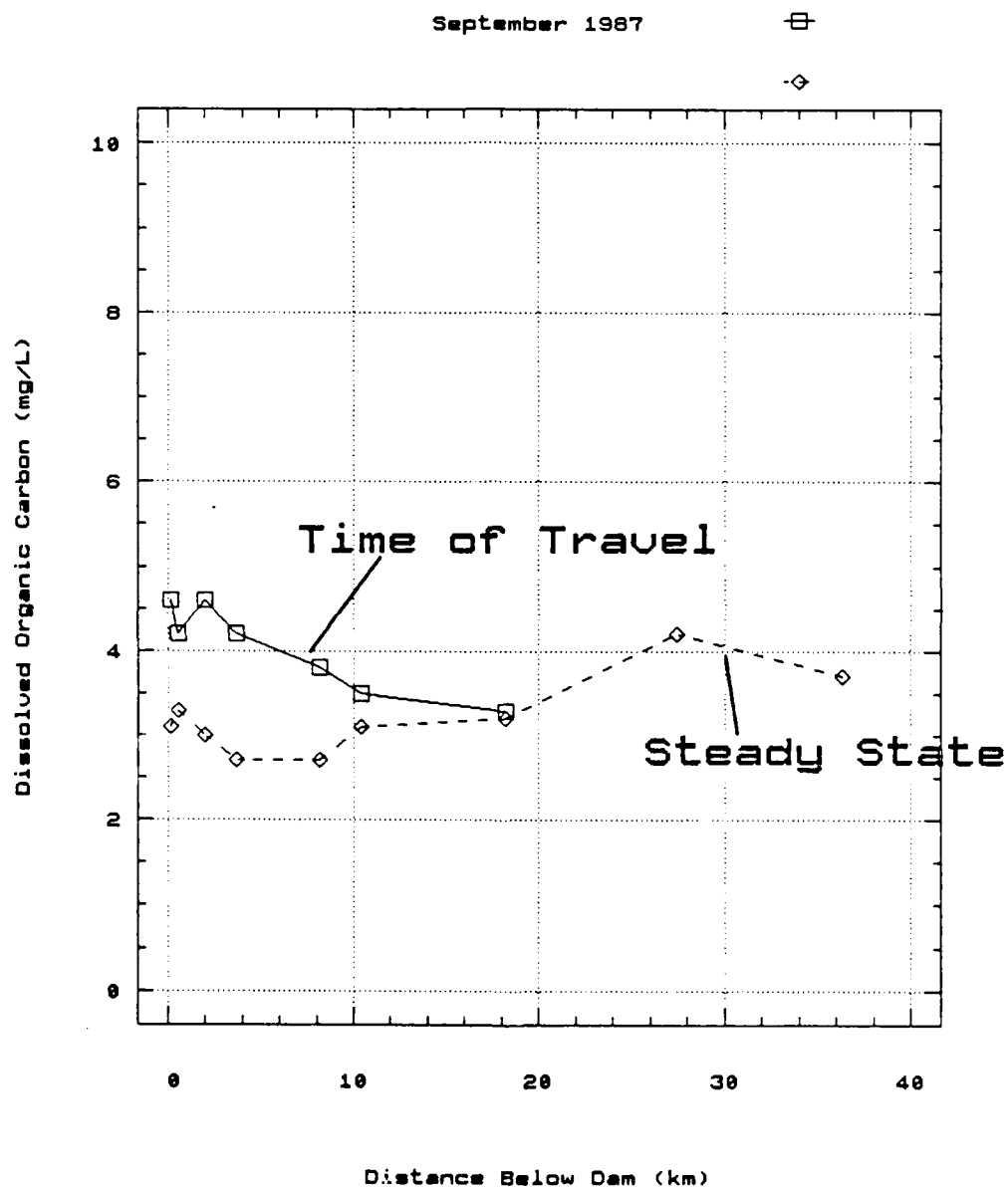
September 1987

Figure C29.   Lake Greeson tailwater, dissolved
organic carbc 1 versus distance below dam for
time-of-travel and steady-state sampling,
9/12/87-9/14/87

GREESON TAILWATER
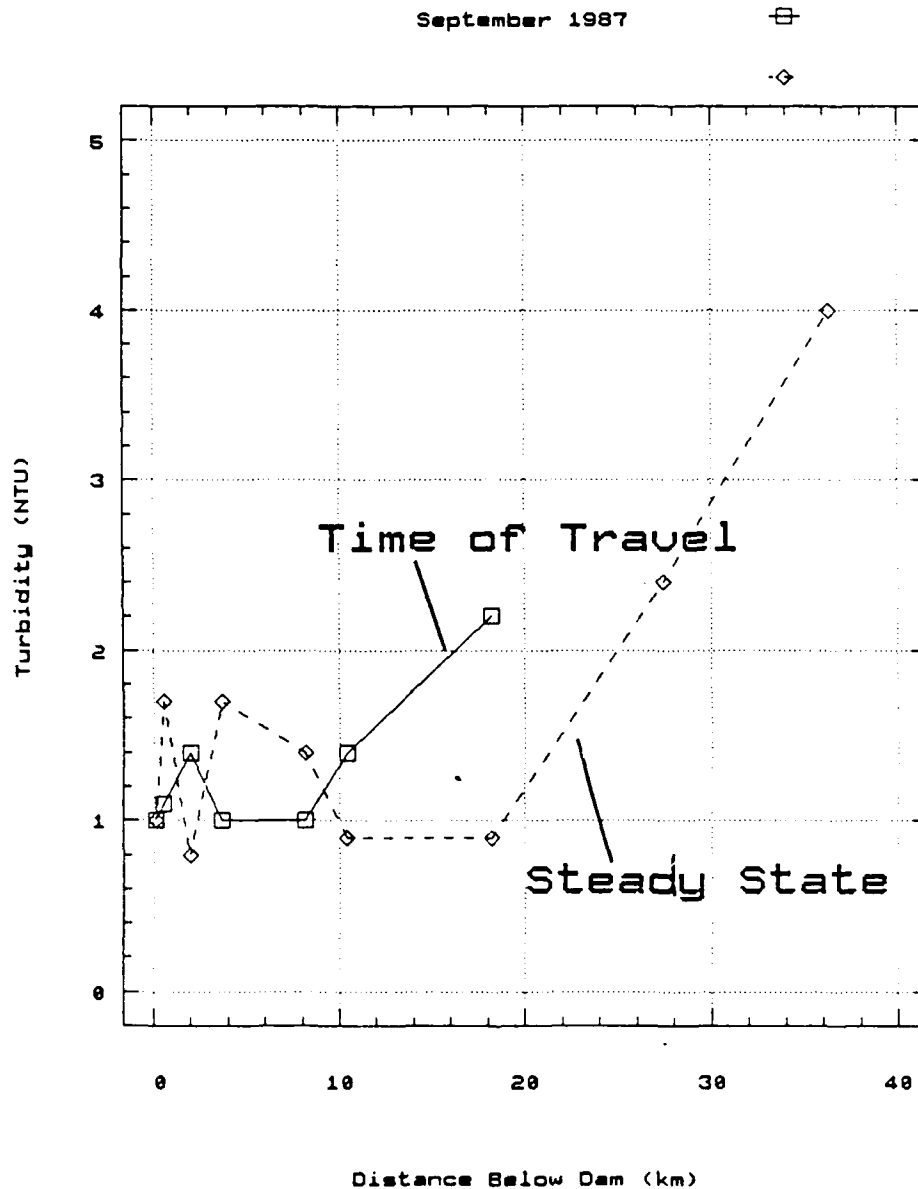
September 1987

Figure C30. Lake Greeson tailwater, turbidity
versus distance below dam for time-of-travel
and steady-state sampling, 9/12/87-9/14/87

GREESON TAILWATER
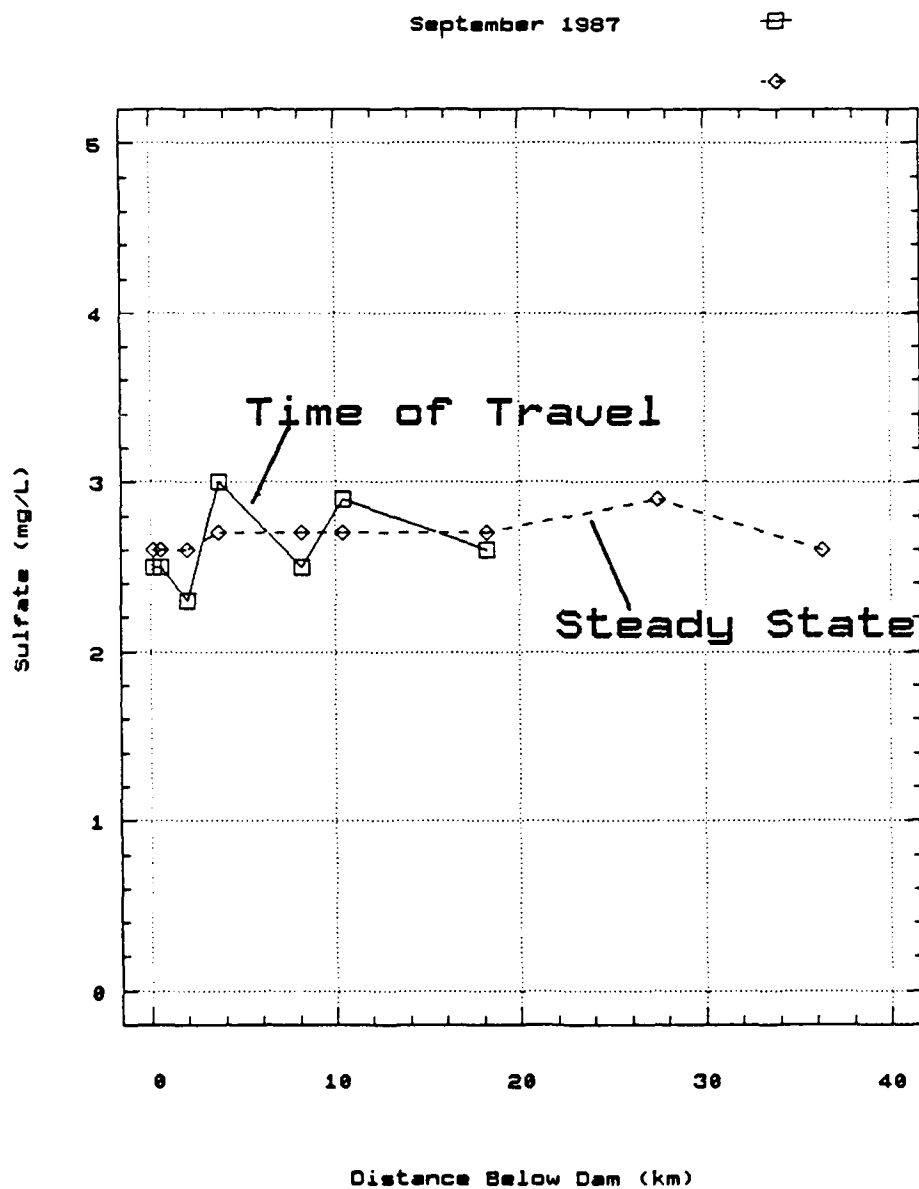
September 1987

Figure C31. Lake Greeson tailwater, sulfate
versus distance below dam for time-of-travel
and steady-state sampling, 9/12/87-9/14/87

GREESON TAILWATER
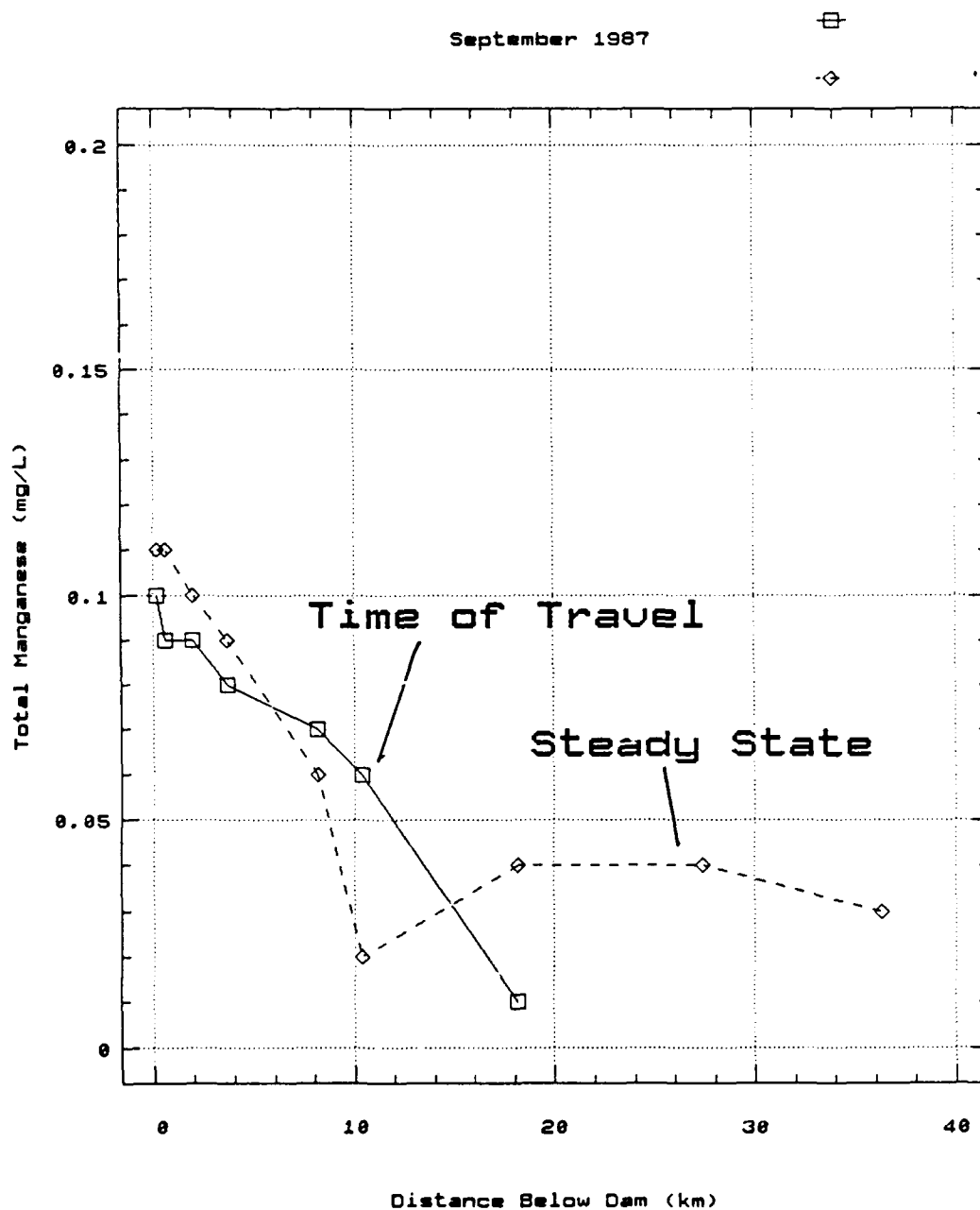
September 1987

Figure C32. Lake Greeson tailwater, total
manganese versus distance below dam for
time-of-travel and steady-state sampling,
9/12/87-9/14/87

GREESON TAILWATER
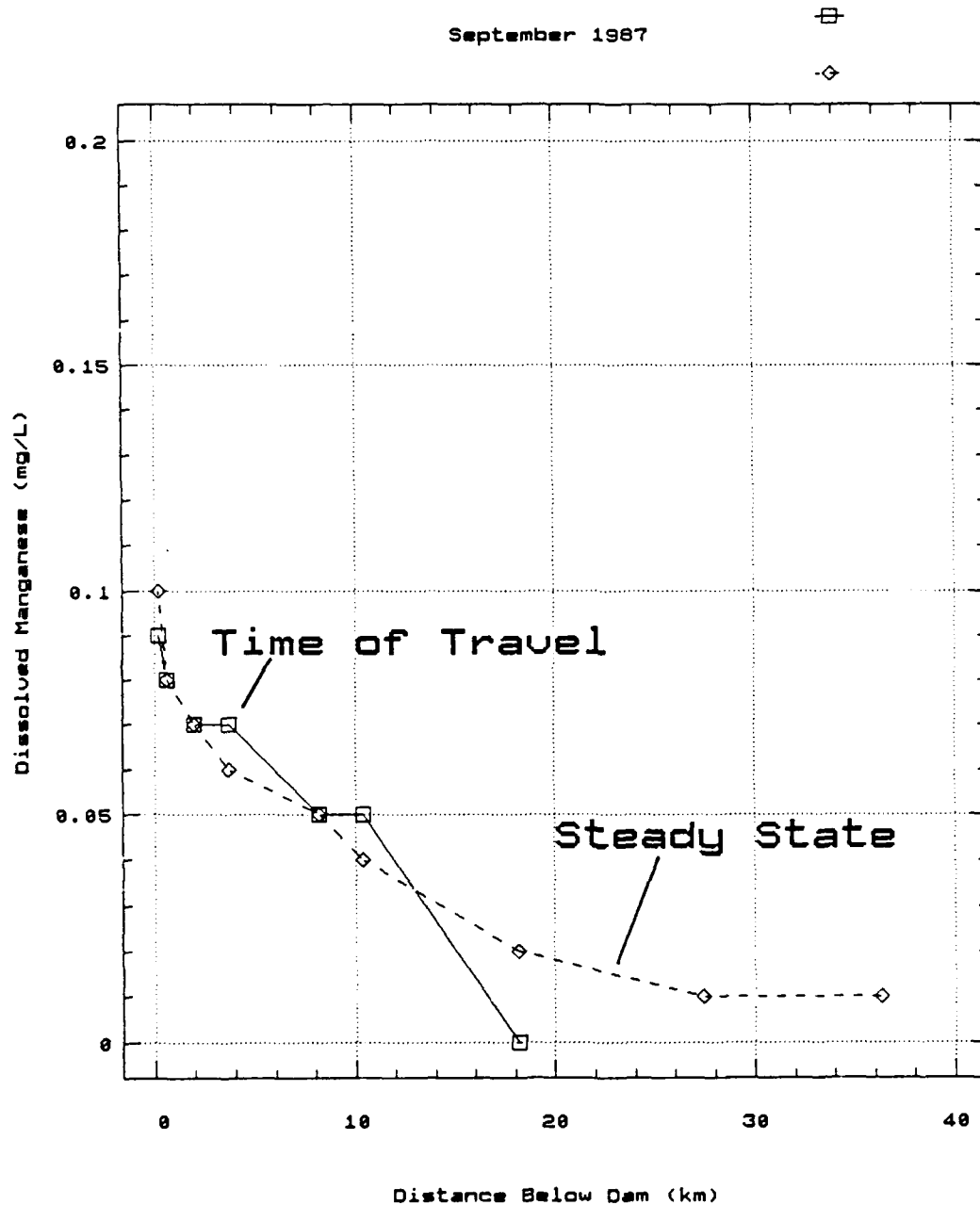
September 1987

Figure C33. Lake Greeson tailwater, dissolved manganese versus distance below dam for time-of-travel and steady-state sampling, 9/12/87-9/14/87

GREESON TAILWATER
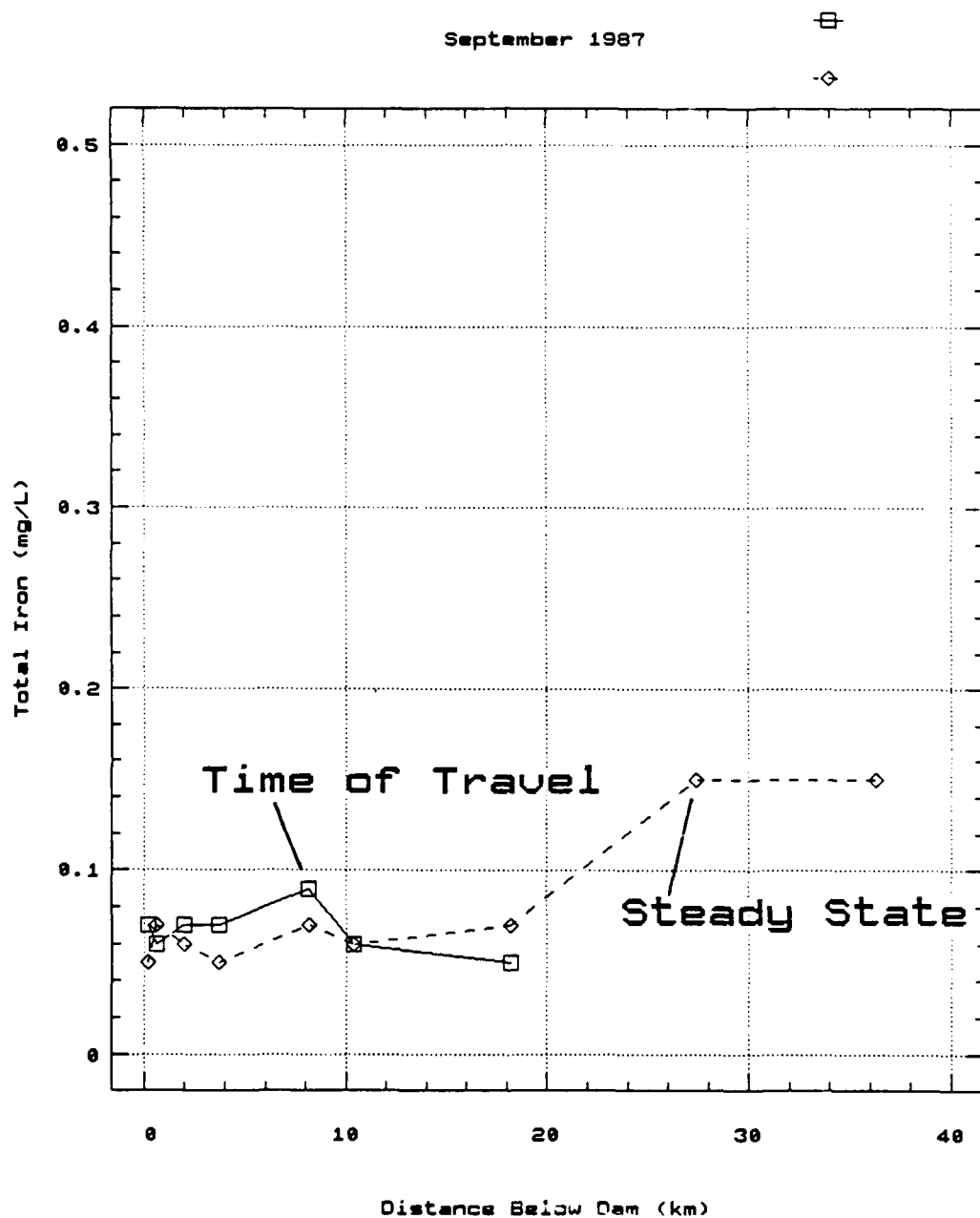
September 1987

Figure C34. Lake Greeson tailwater, total iron
versus distance below dam for time-of-travel
and steady-state sampling, 9/12/87-9/14/87

C34

GREESON TAILWATER

September 1987

Dissolved Iron (mg/L) vs Distance Below Dam (km)

Time of Travel
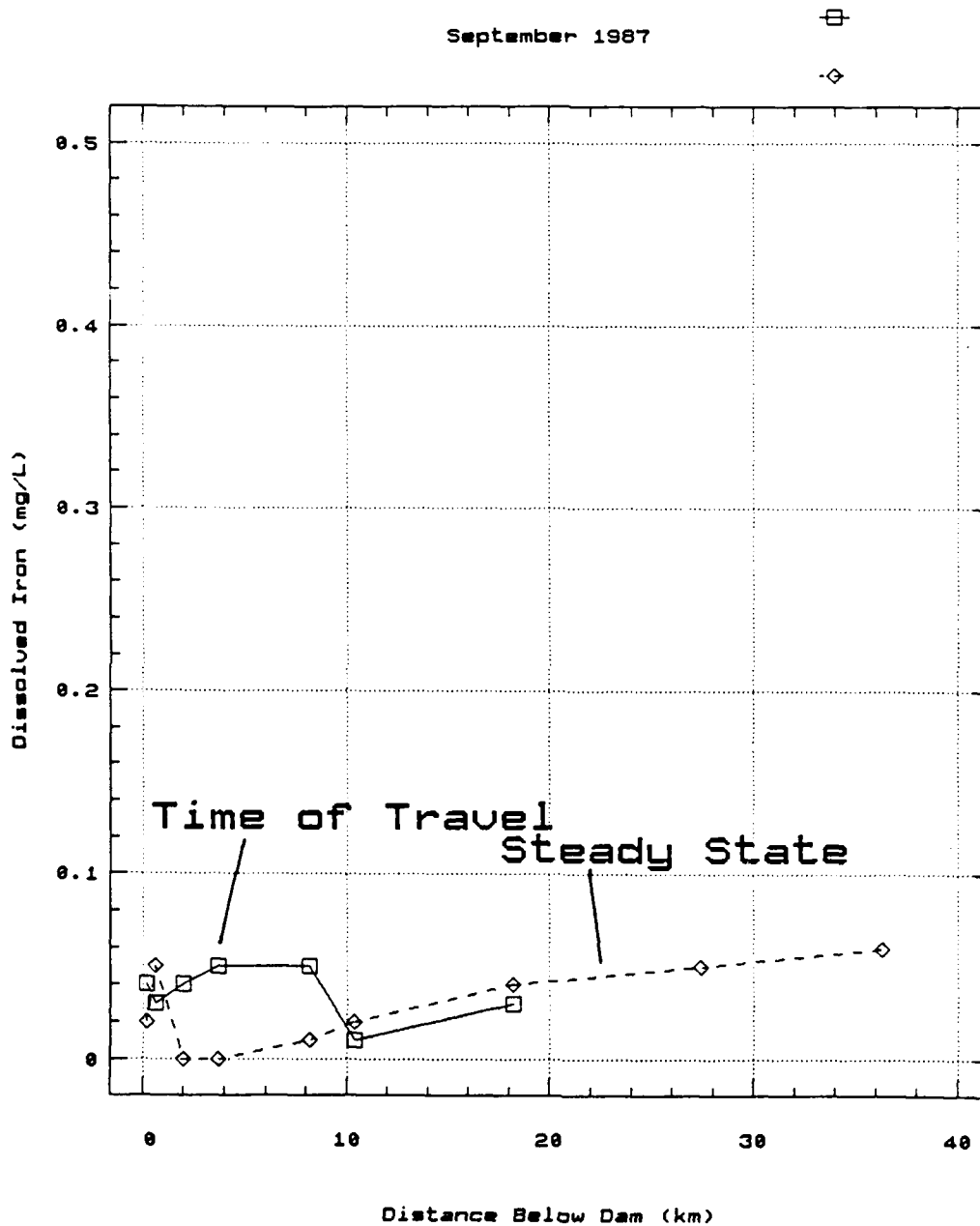
Steady State

Figure C35. Lake Greeson tailwater, dissolved
iron versus distance below dam for time-of-
travel and steady-state sampling, 9/12/87-
9/14/87

C35

GREESON TAILWATER
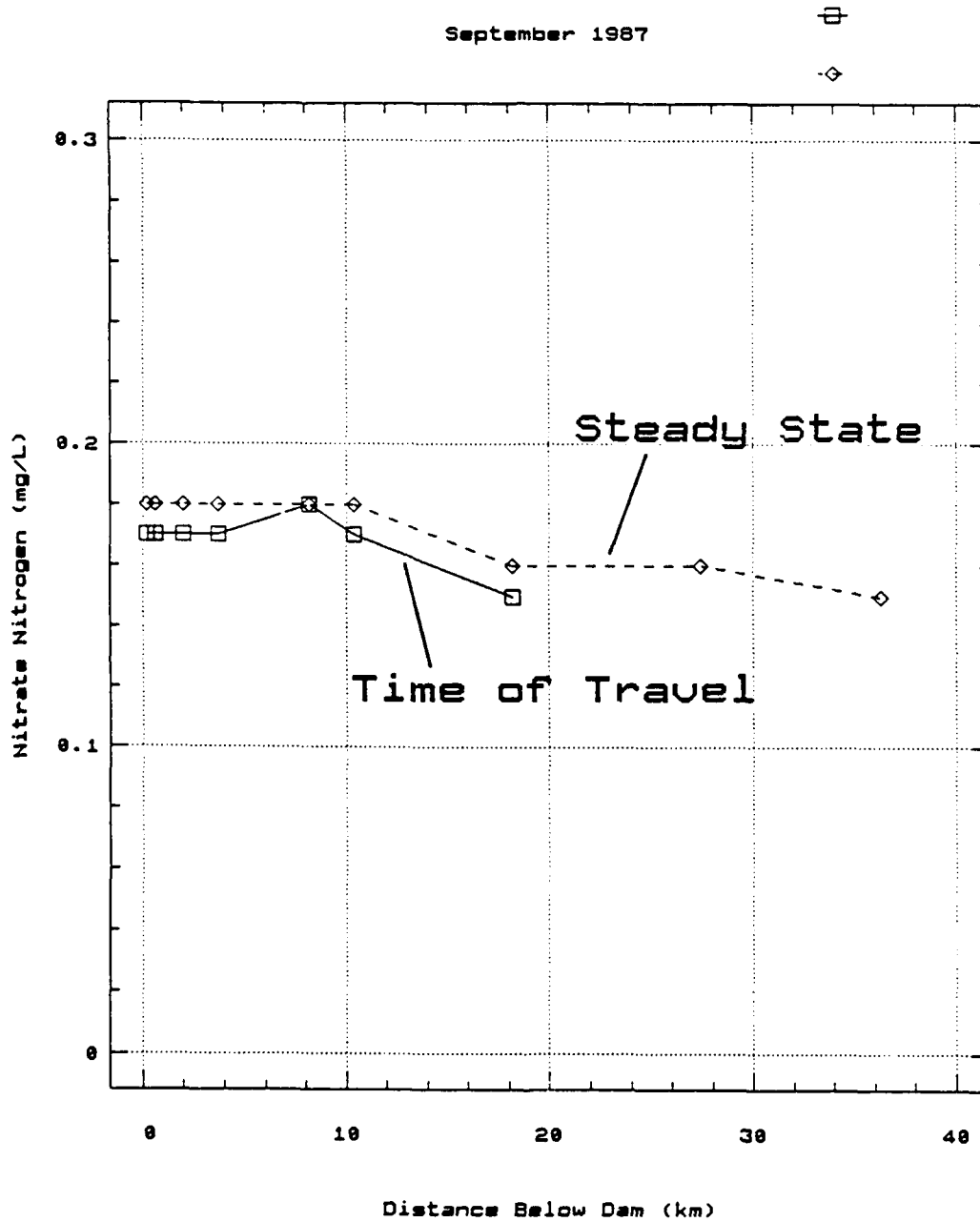
September 1987

Figure C36.   Lake Greeson tailwater, nitrate
nitrogen versus distance below dam for time-
of-travel and steady-state sampling,
9/12/87-9/14/87
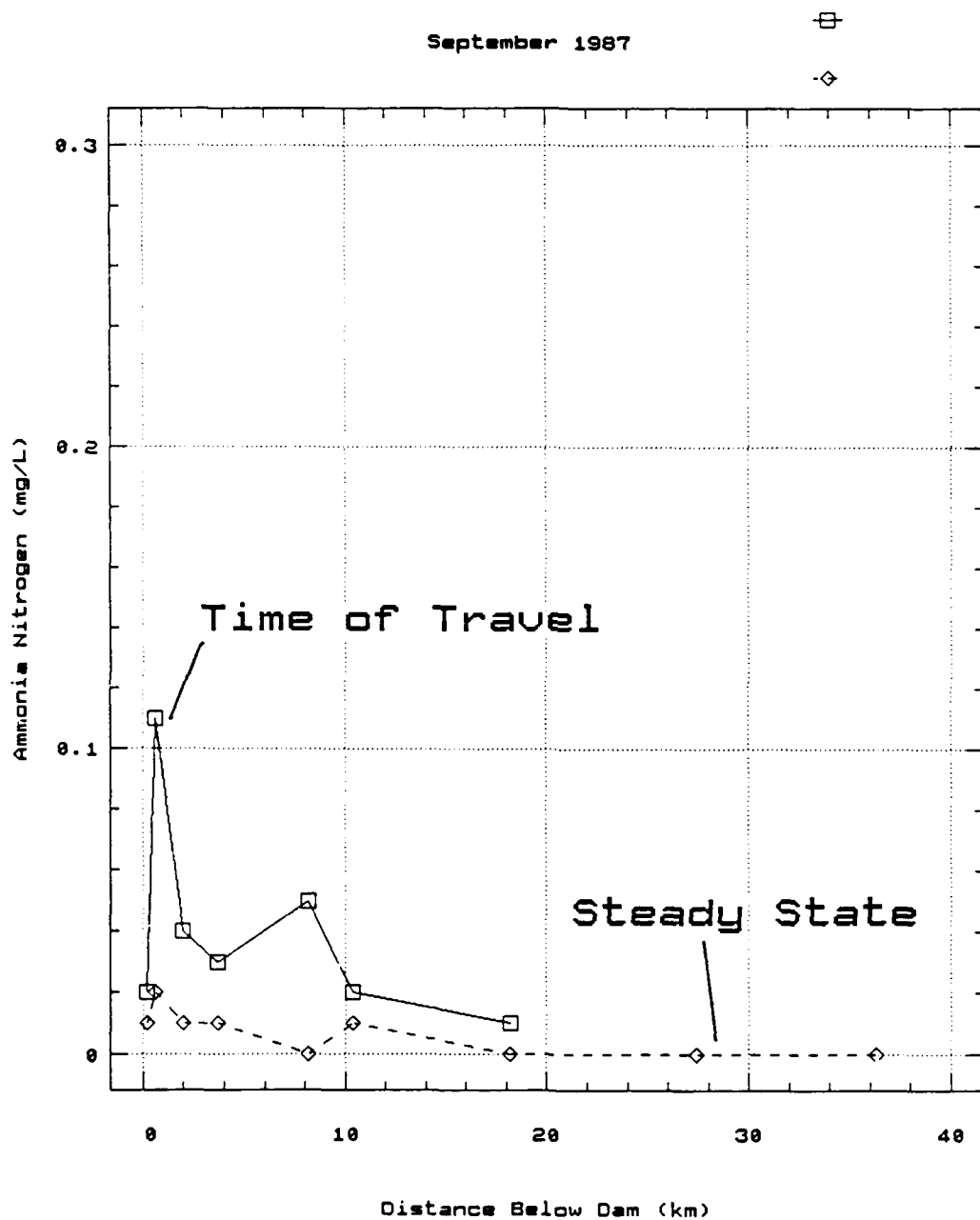
Figure C37. Lake Greeson tailwater, ammonia
nitrogen versus distance below dam for time-
of-travel and steady-state sampling,
9/12/87-9/14/87

GREESON TAILWATER
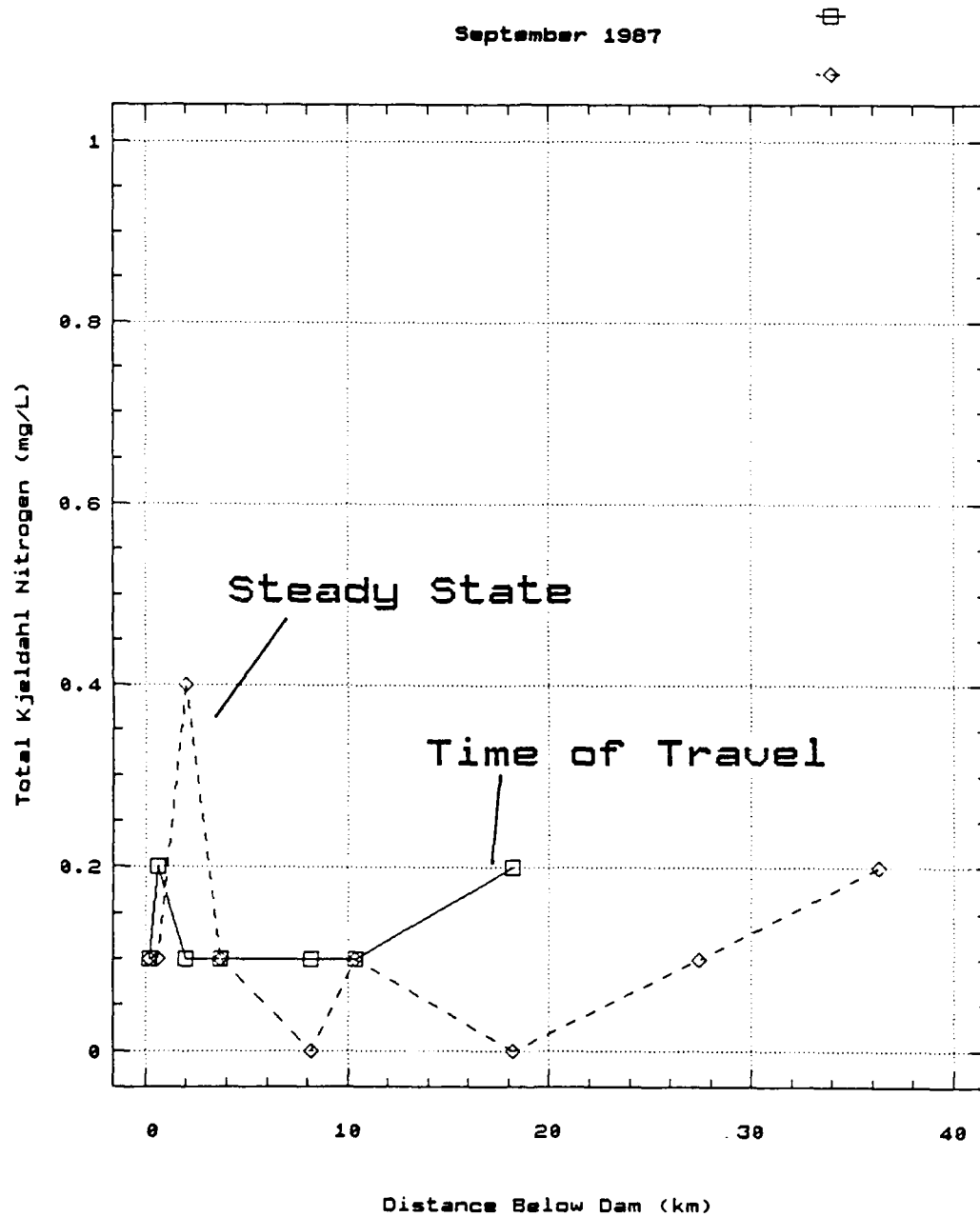
September 1987

Figure C38. Lake Greeson tailwater, total
Kjeldahl nitrogen versus distance below
dam for time-of-travel and steady-state
sampling, 9/12/87-9/14/87

GREESON TAILWATER

September 1987
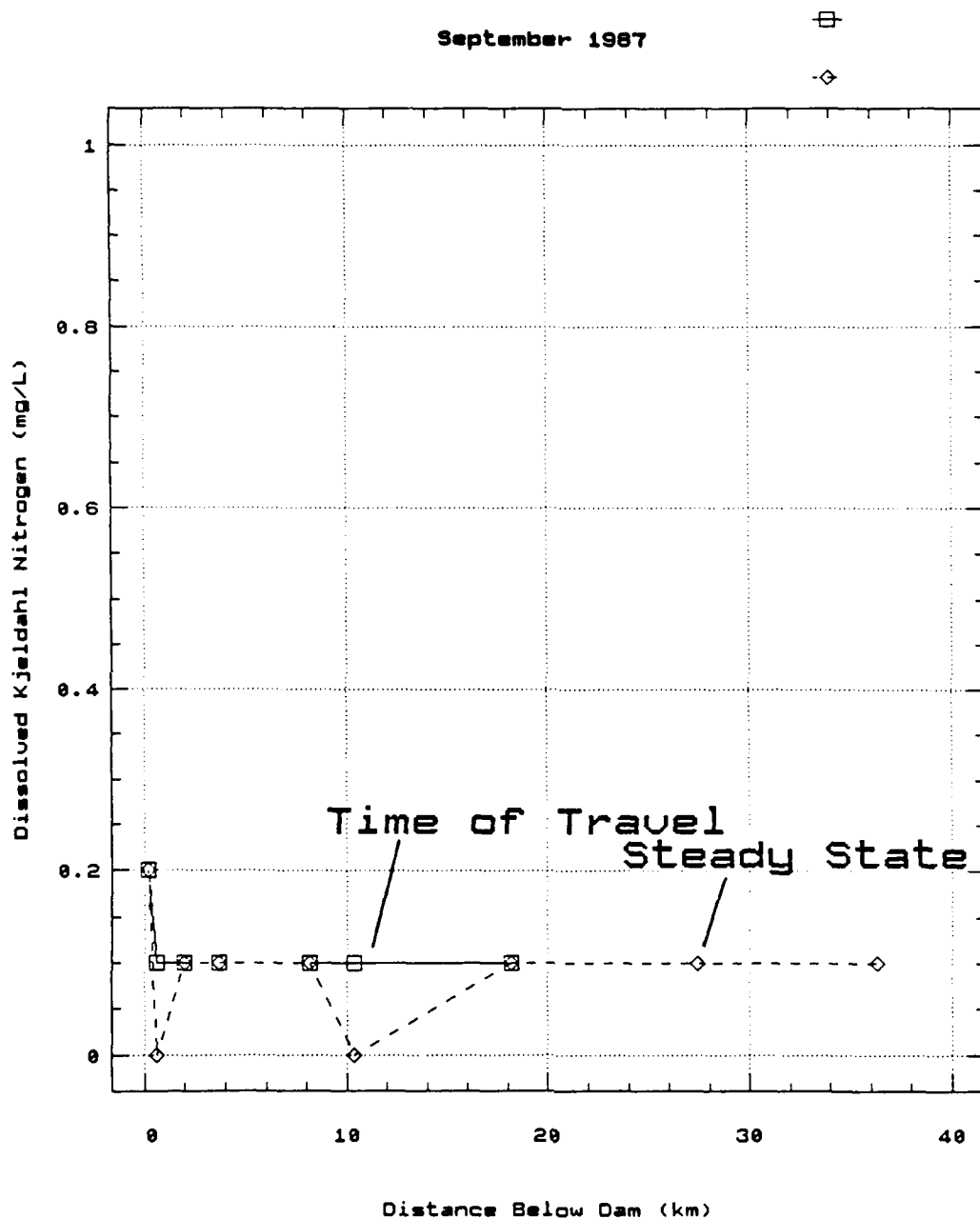
Figure C39. Lake Greeson tailwater, dissolved Kjeldahl nitrogen versus distance below dam for time-of-travel and steady-state sampling, 9/12/87-9/14/87

Lake Greeson
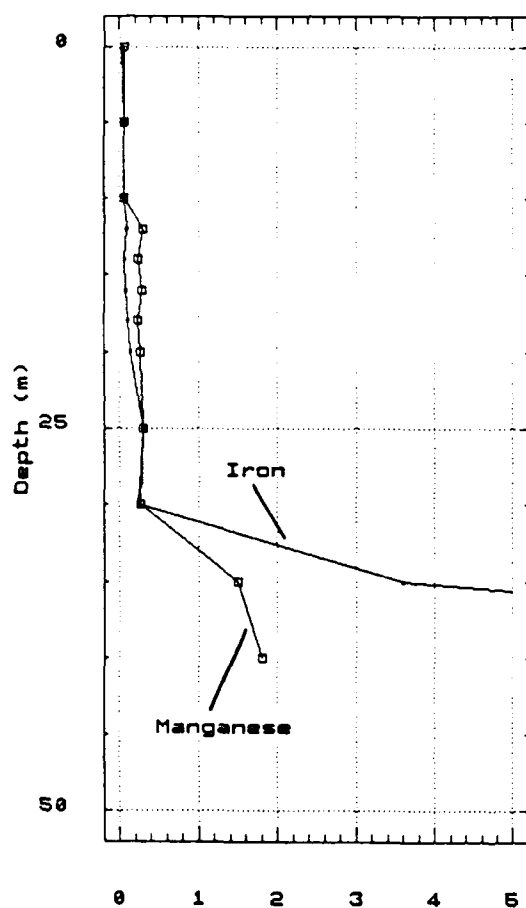
10/14/87

Figure C40. Lake Greeson (station 1) iron and manganese profiles on 10/14/87

Lake Greeson

10/14/87

Nitrate

Ammonia

Depth (m)

0

25

50

0   0.75   1.5
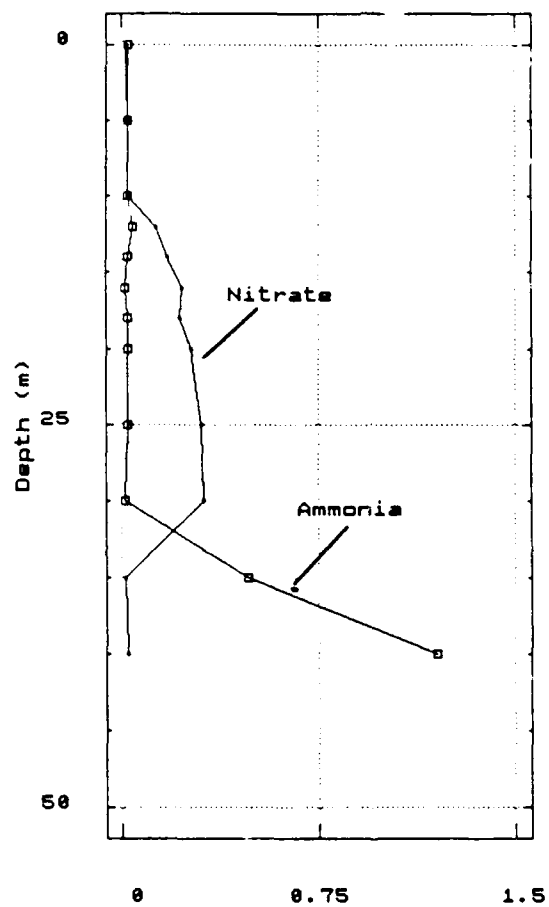
Nitrogen (mg/L)

Figure C41.   Lake Greeson (sta-
tion 1) ammonia nitrogen and
nitrate nitrogen profiles
on 10/14/87

GREESON TAILWATER
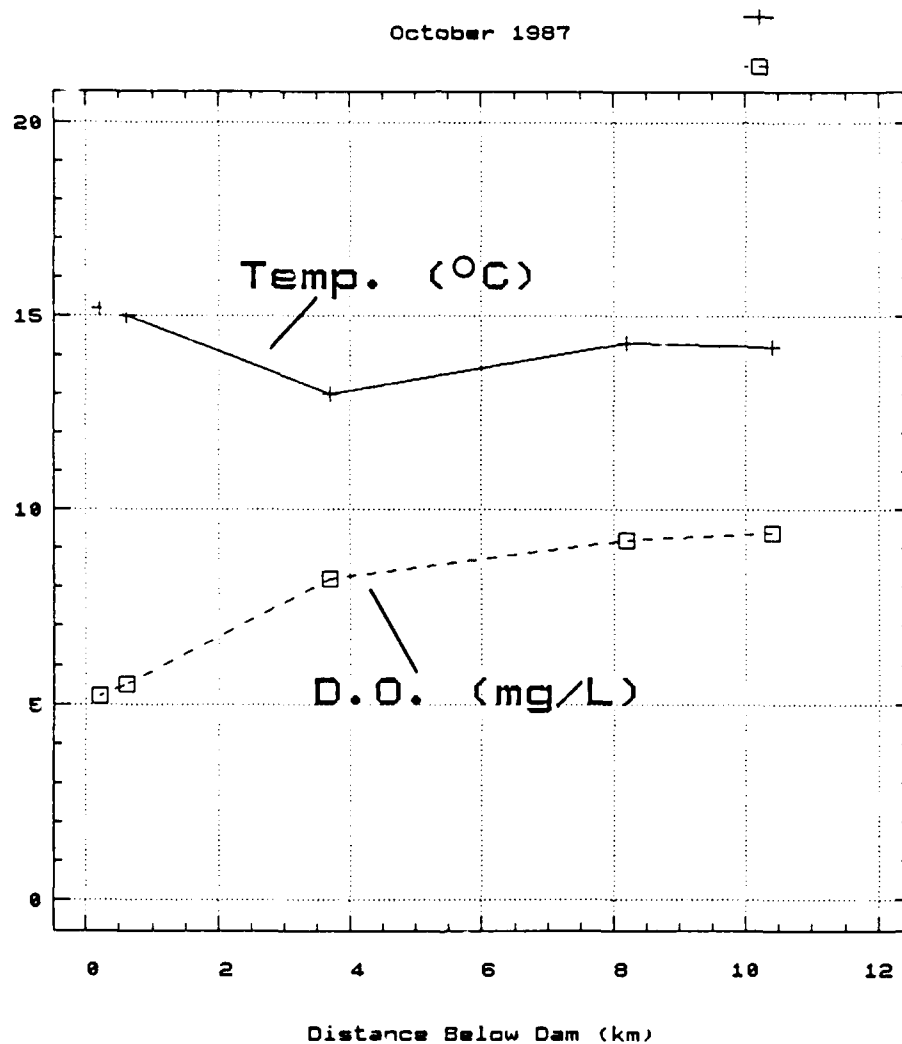
October 1987

Figure C42. Lake Greeson tailwater, temperature and DO versus distance below dam on 10/14/87

GREESON TAILWATER
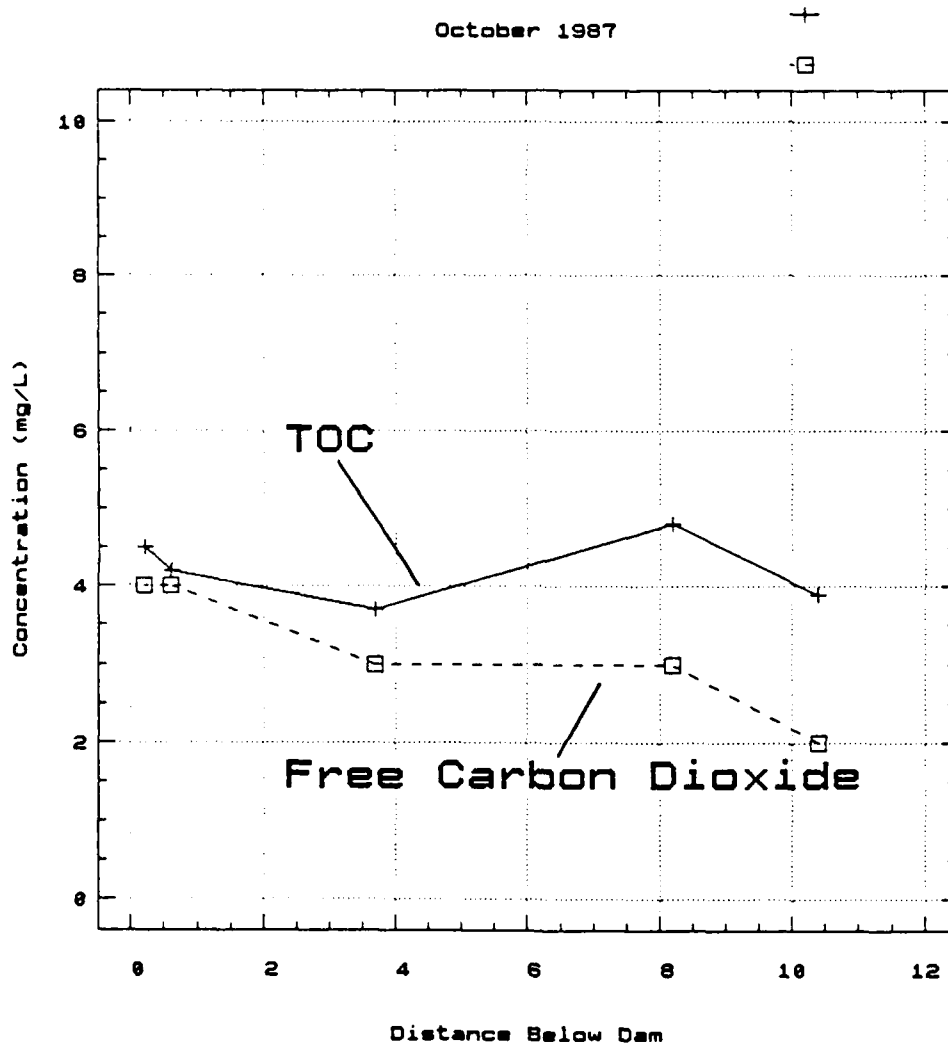
October 1987

Figure C43. Lake Greeson tailwater, total
organic carbon and free CO_2 versus distance
below dam on 10/14/87

GREESON TAILWATER
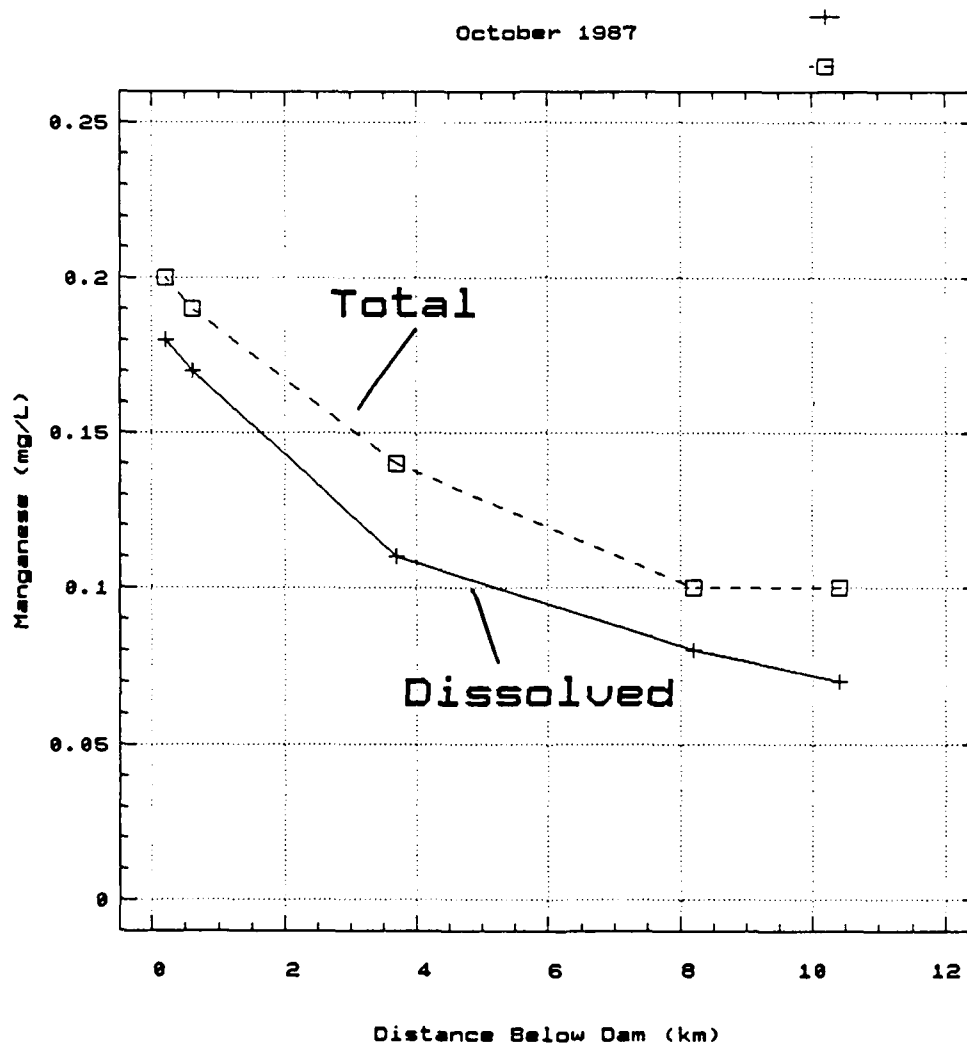
October 1987

Figure C44. Lake Greeson tailwater, total
and dissolved manganese versus distance
below dam on 10/14/87

GREESON TAILWATER
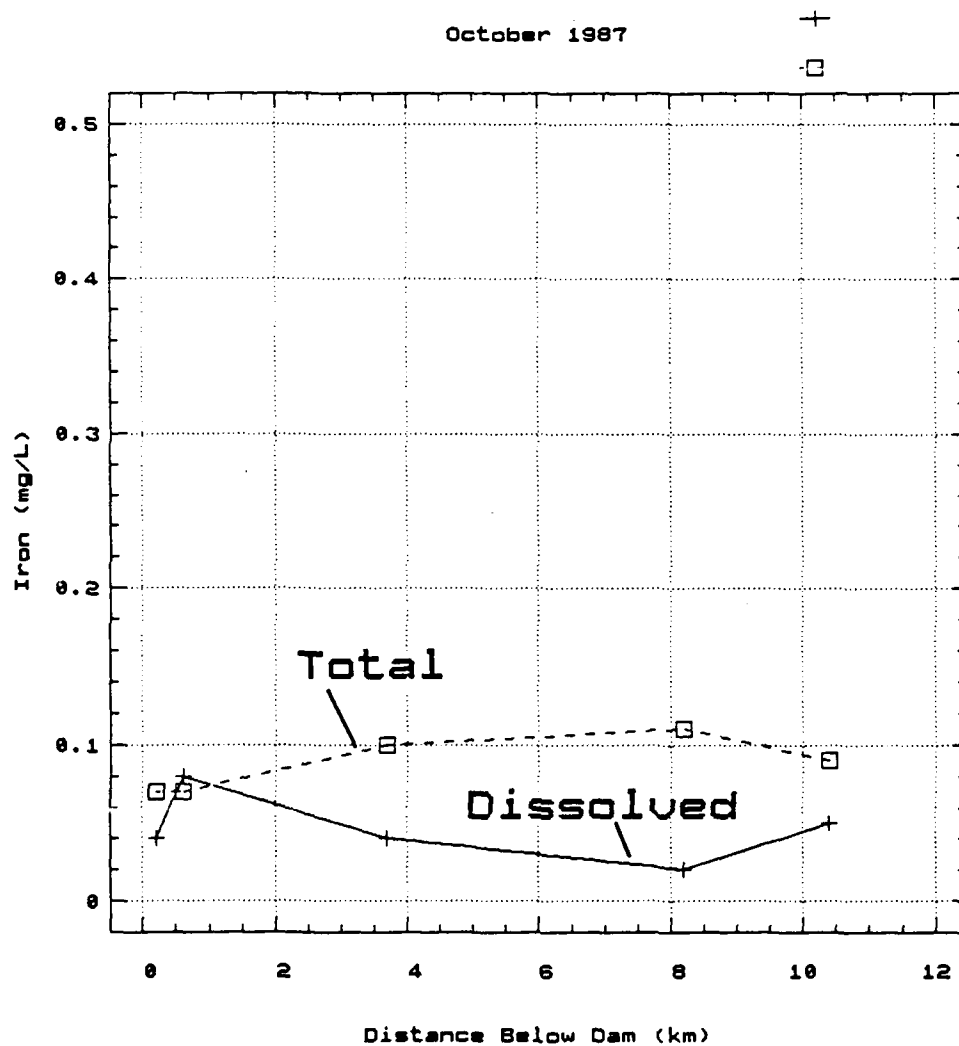
October 1987

Figure C45. Lake Greeson tailwater, total
and dissolved iron versus distance below
dam on 10/14/87

GREESON TAILWATER

October 1987
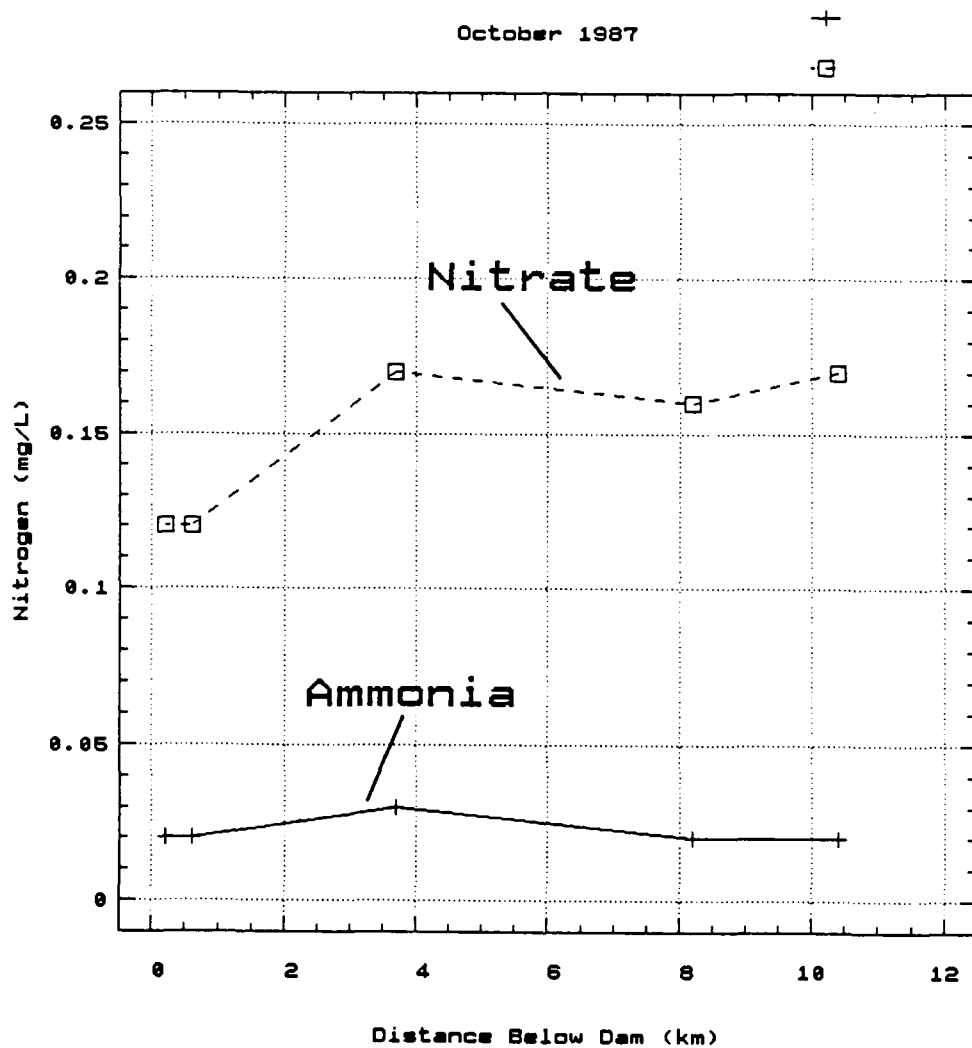
Figure C46. Lake Greeson tailwater,
ammonia nitrogen and nitrate nitrogen
versus distance below dam on 10/14/87

LAKE GREESON

10 Day BOD

✳ 3 m

⊟ 9 m

◇ 41 m
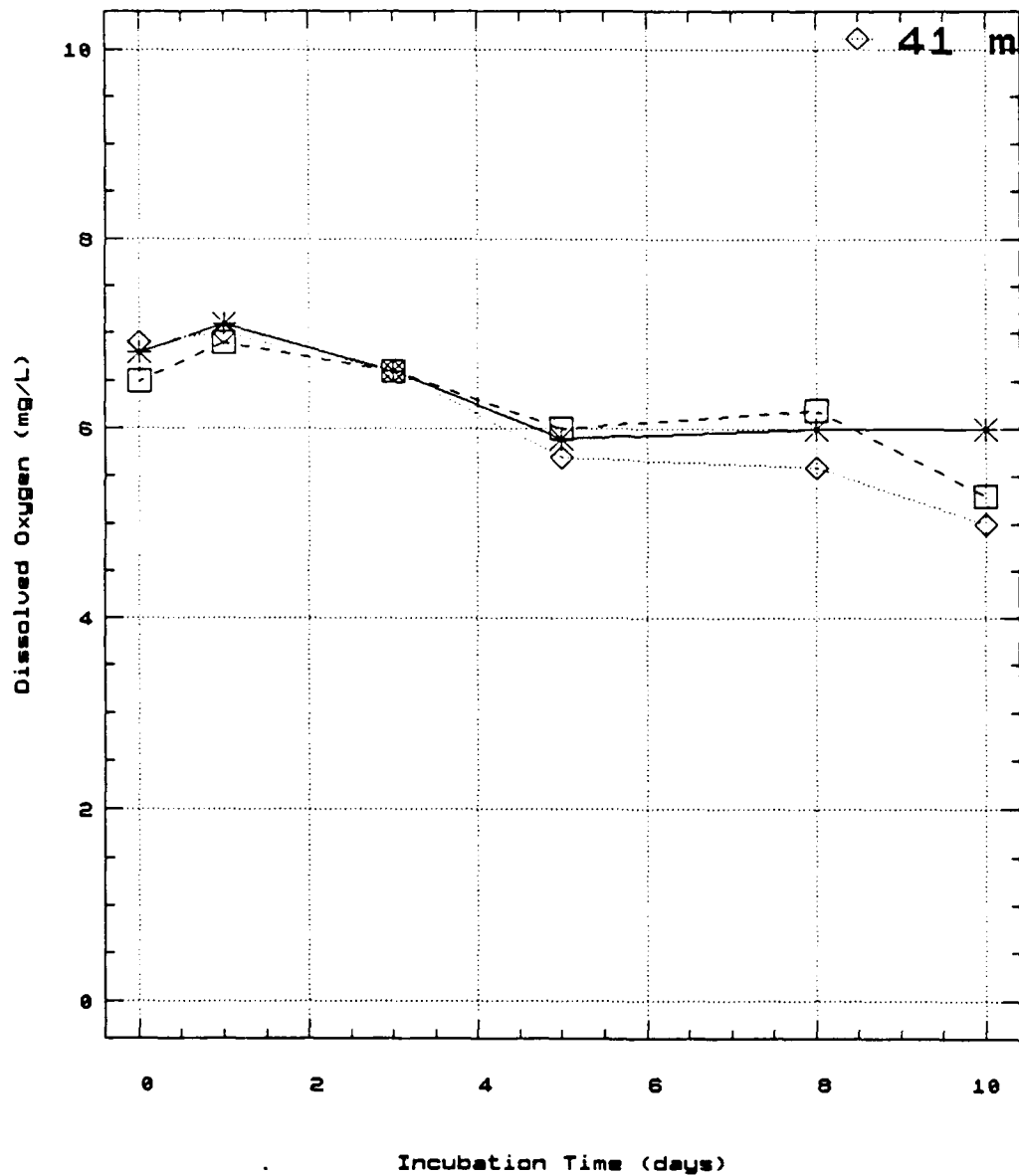
Figure C47.   Lake Greeson, 10-day BOD, mean
dissolved oxygen initiated August 25, 1987
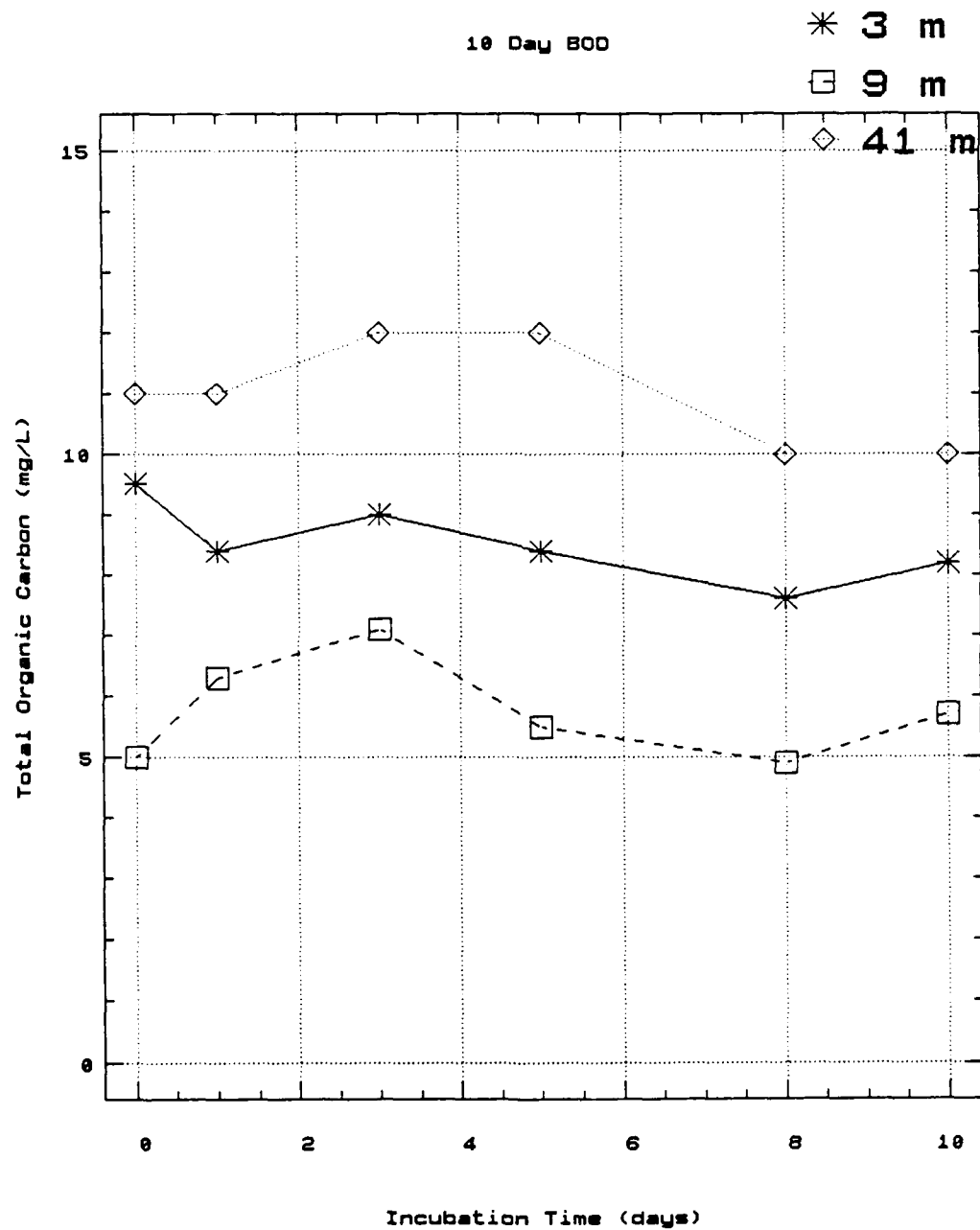
Figure C48. Lake Greeson, August 25, 1987,
10-day BOD, mean total organic carbon

Figure C49. Lake Greeson, August 25, 1987.
10-day BOD, mean dissolved iron
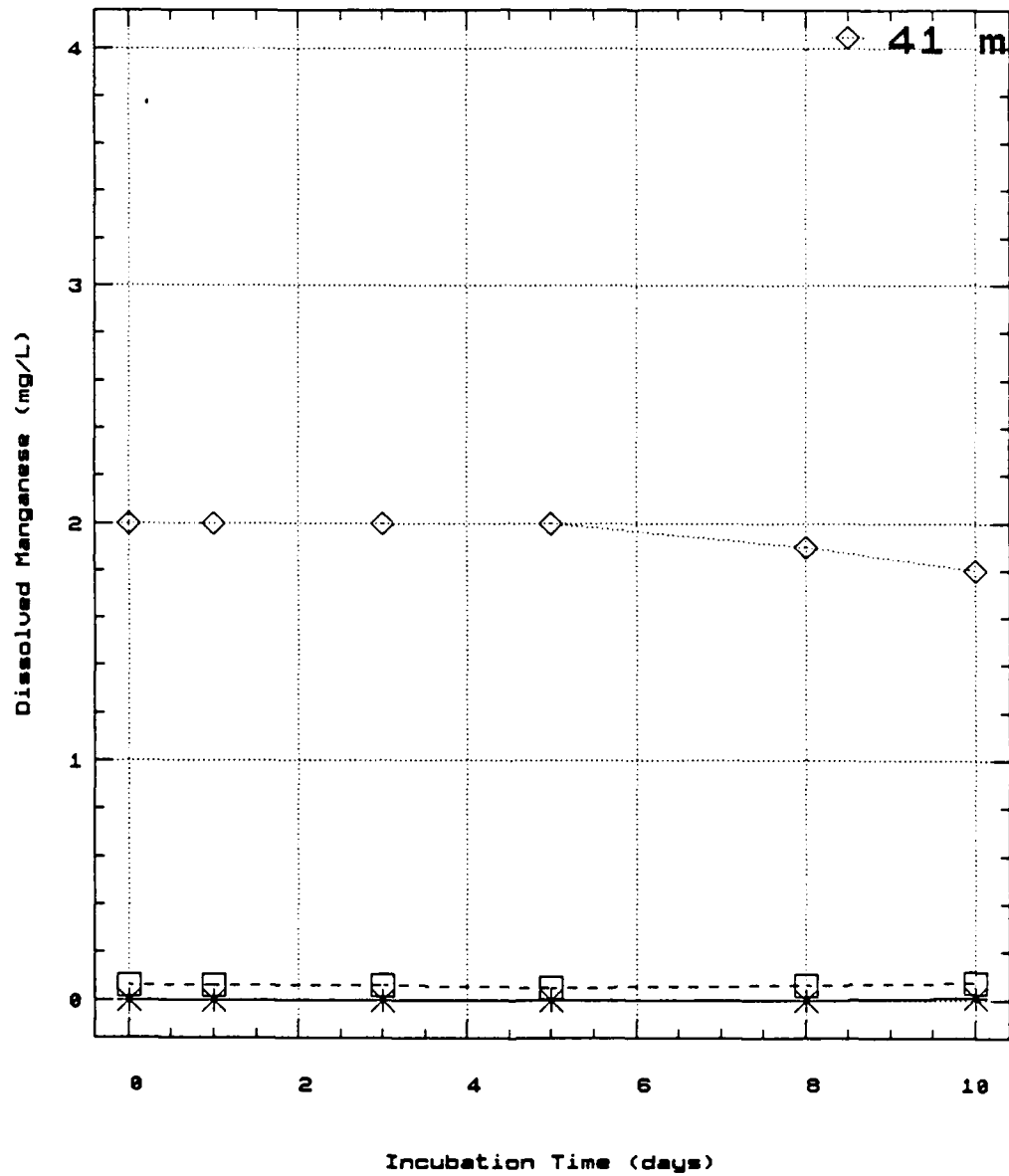
Figure C50. Lake Greeson, August 25, 1987.
10-day BOD, mean dissolved manganese
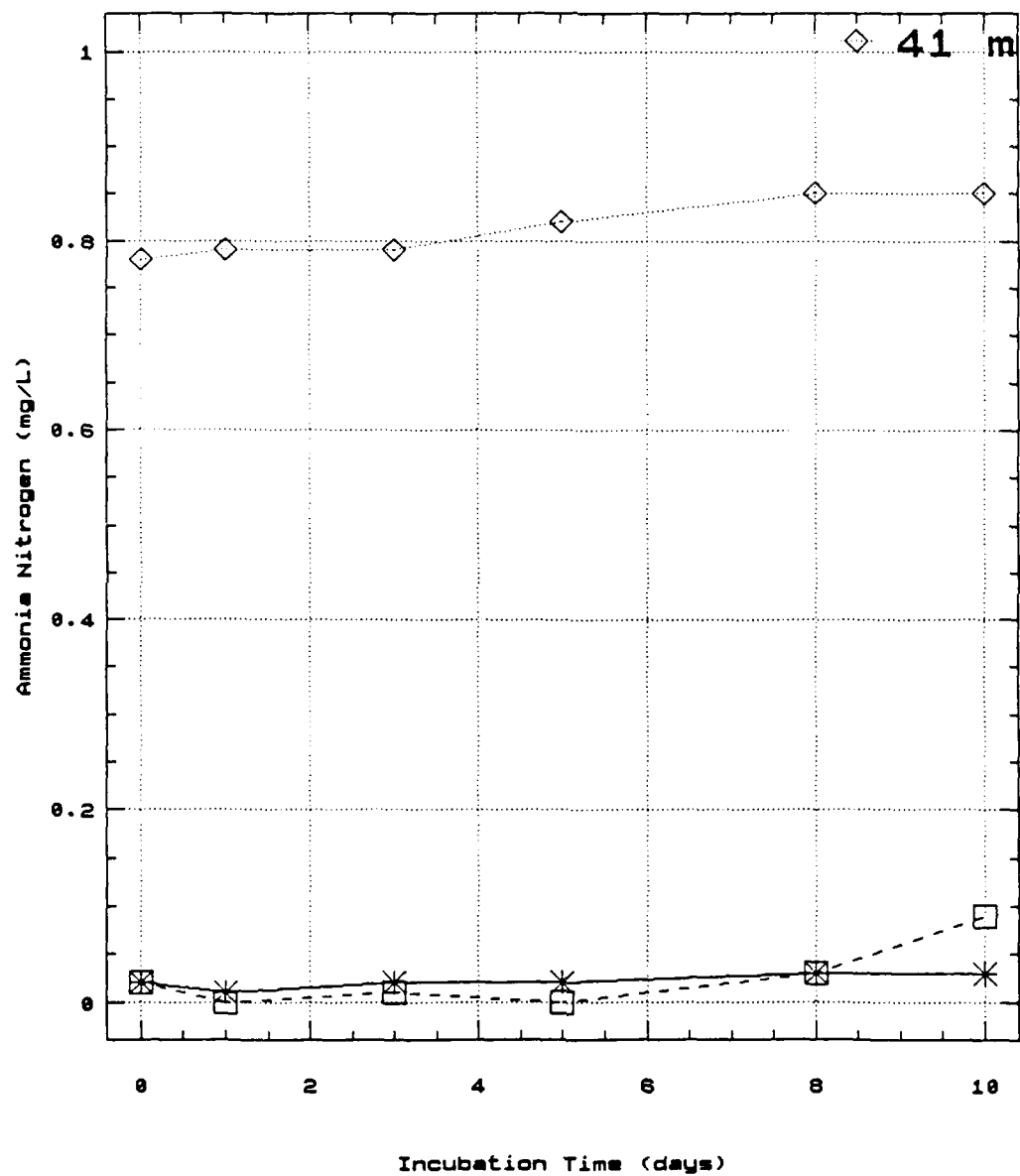
Figure C51.   Lake Greeson, August 25, 1987.
10-day BOD, mean ammonia nitrogen

C51

Figure C52. Lake Greeson, August 25, 1987.
10-day BOD, mean nitrate nitrogen

LAKE GREESON

10 Day BOD

* 4 m

▣ 14 m

◇ 39 m
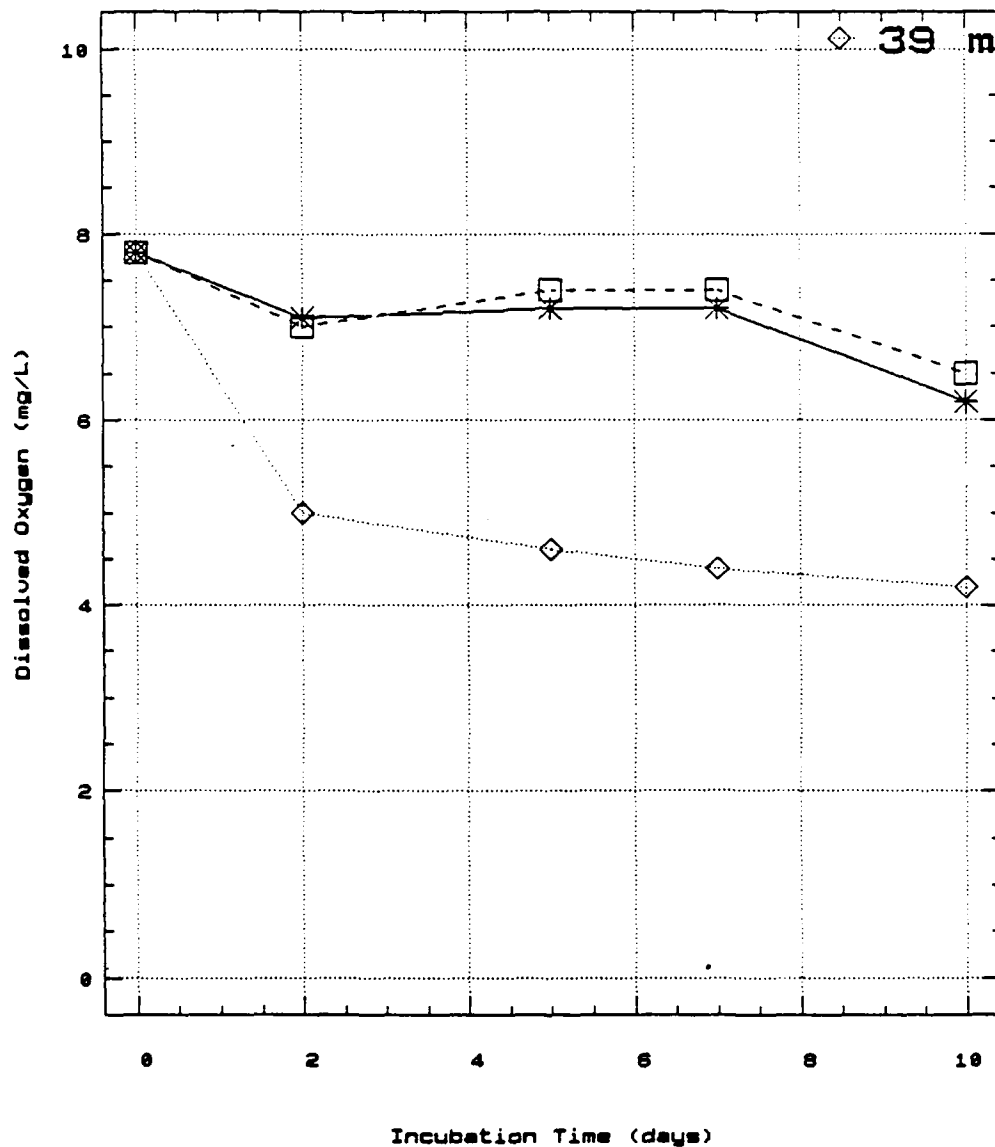
Figure C53. Lake Greeson, November 4, 1987.
10-day BOD, mean dissolved oxygen

C53
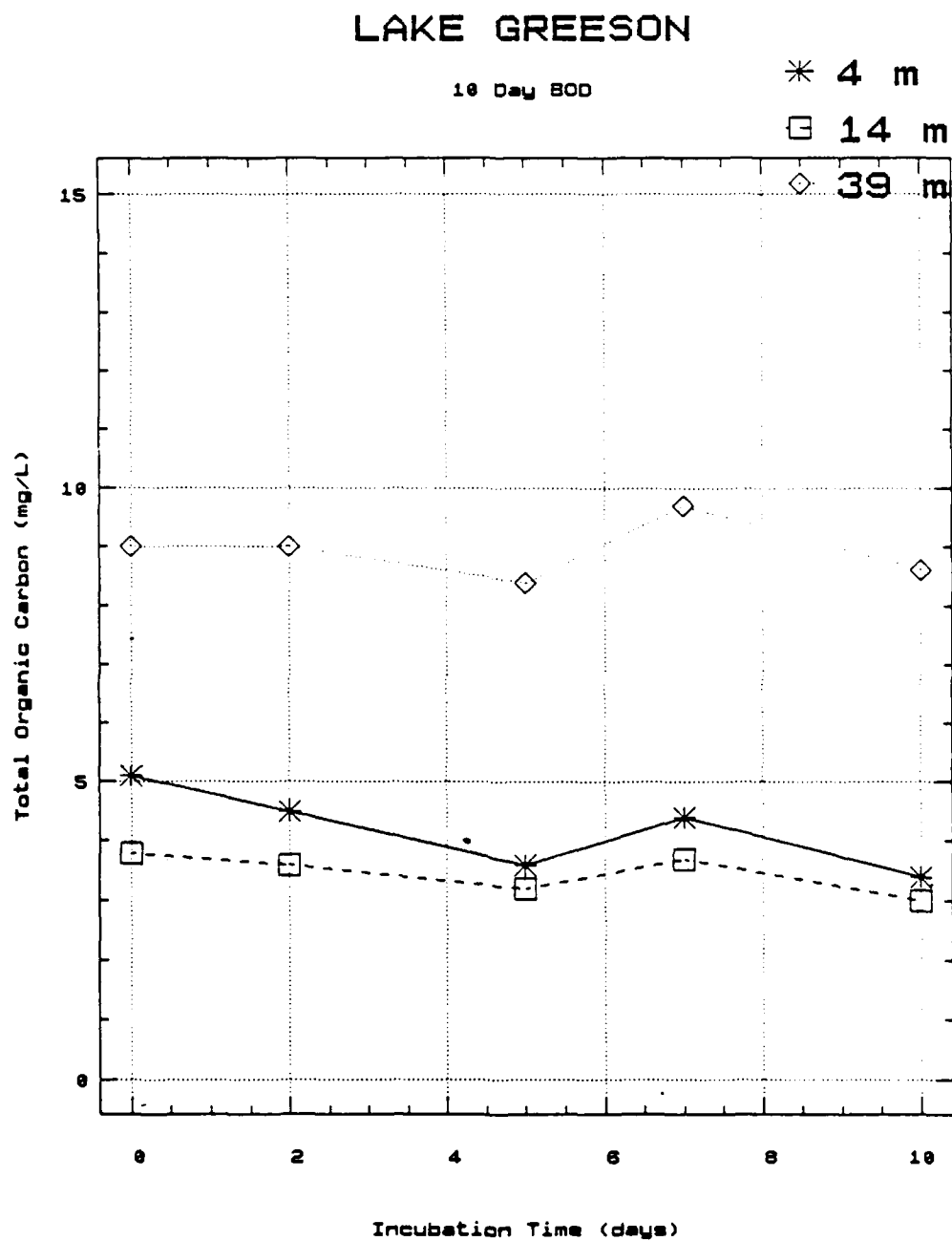
Figure C54. Lake Greeson, November 4, 1987.
10-day BOD, mean total organic carbon

LAKE GREESON

10 Day BOD

✳ 4 m
▣ 14 m
◇ 39 m
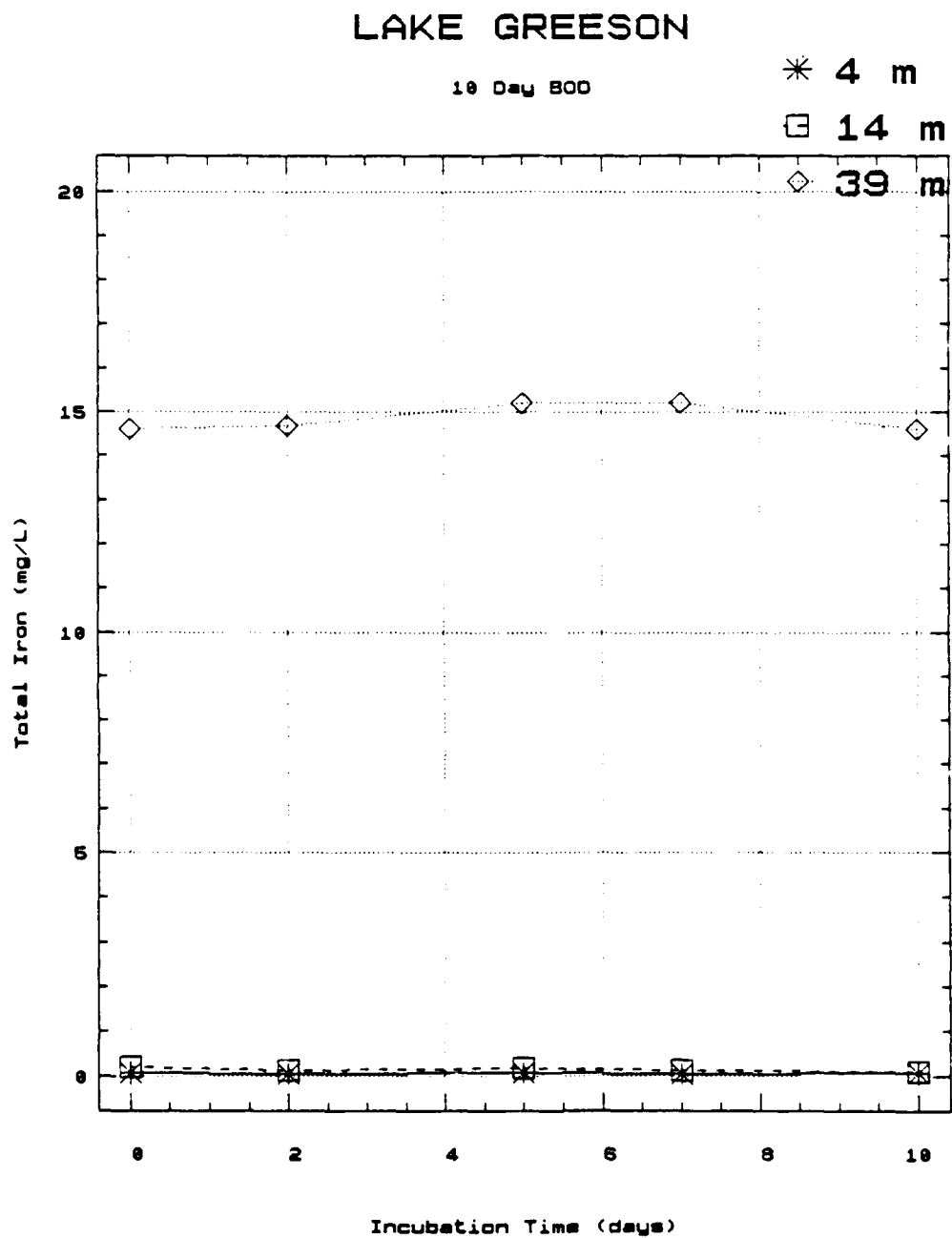
Figure C55. Lake Greeson, November 4, 1987.
10-day BOD, mean total iron
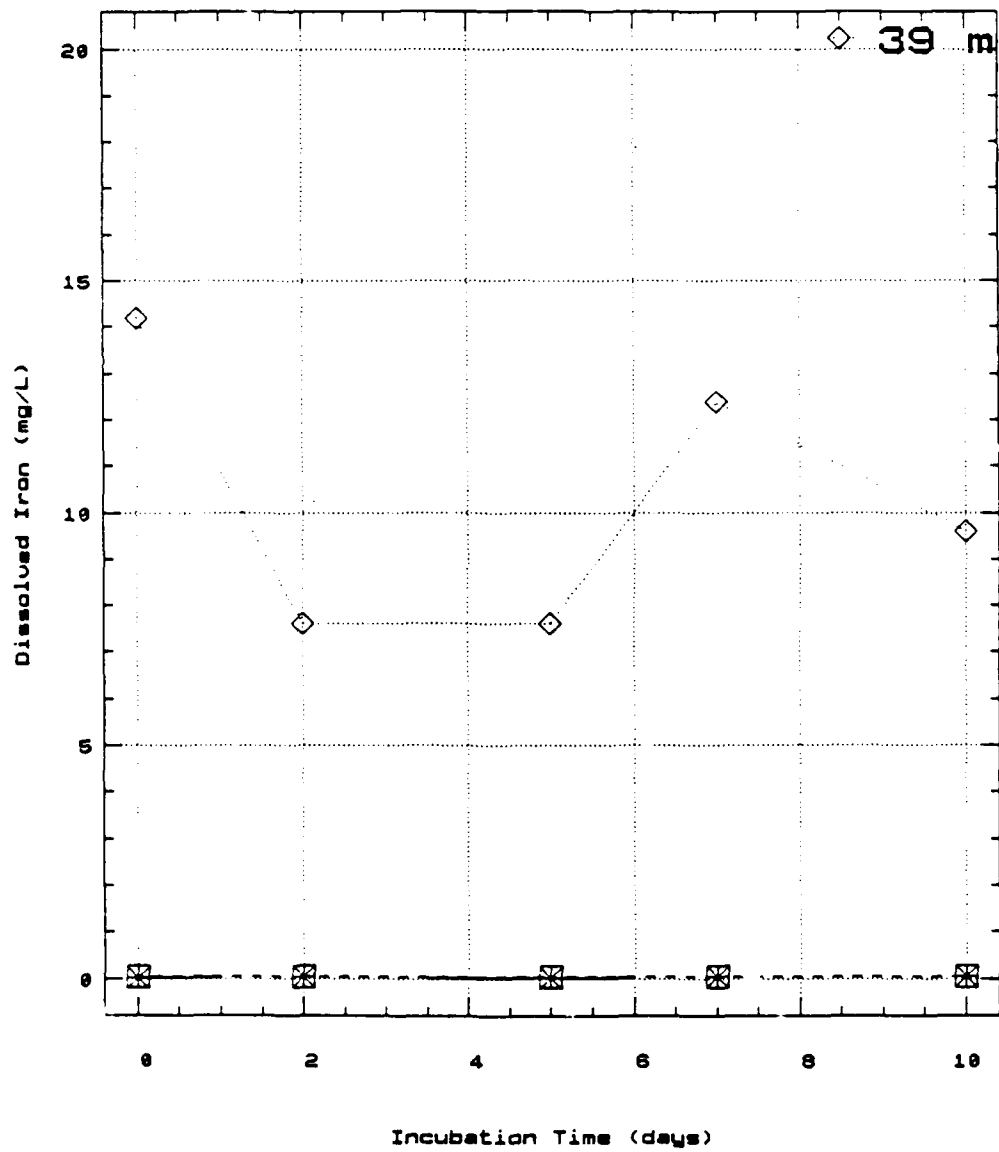
Figure C56. Lake Greeson, November 4, 1987.
10-day BOD, mean dissolved iron
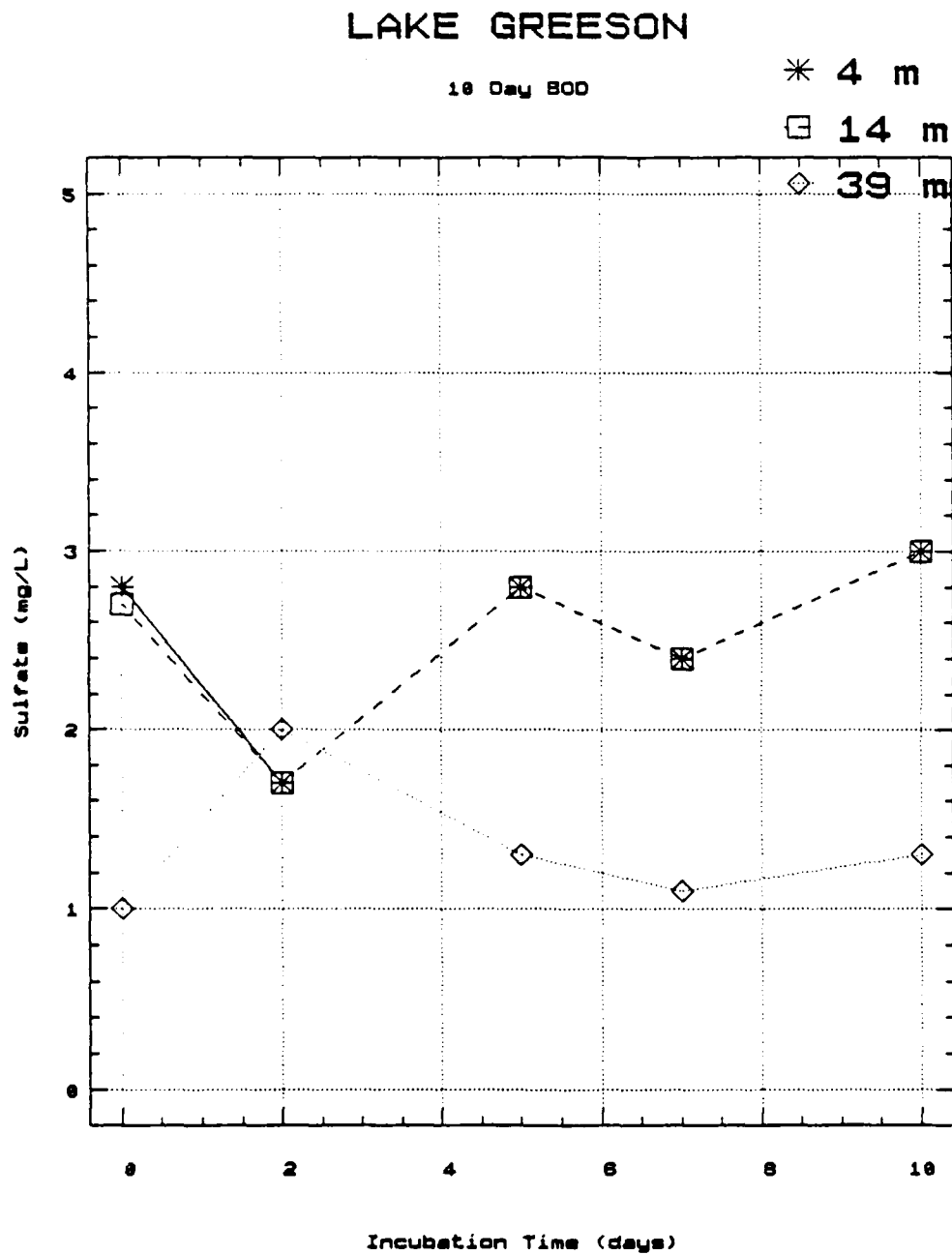
Figure C57.   Lake Greeson, November 4, 1987.
10-day BOD, mean sulfate

LAKE GREESON
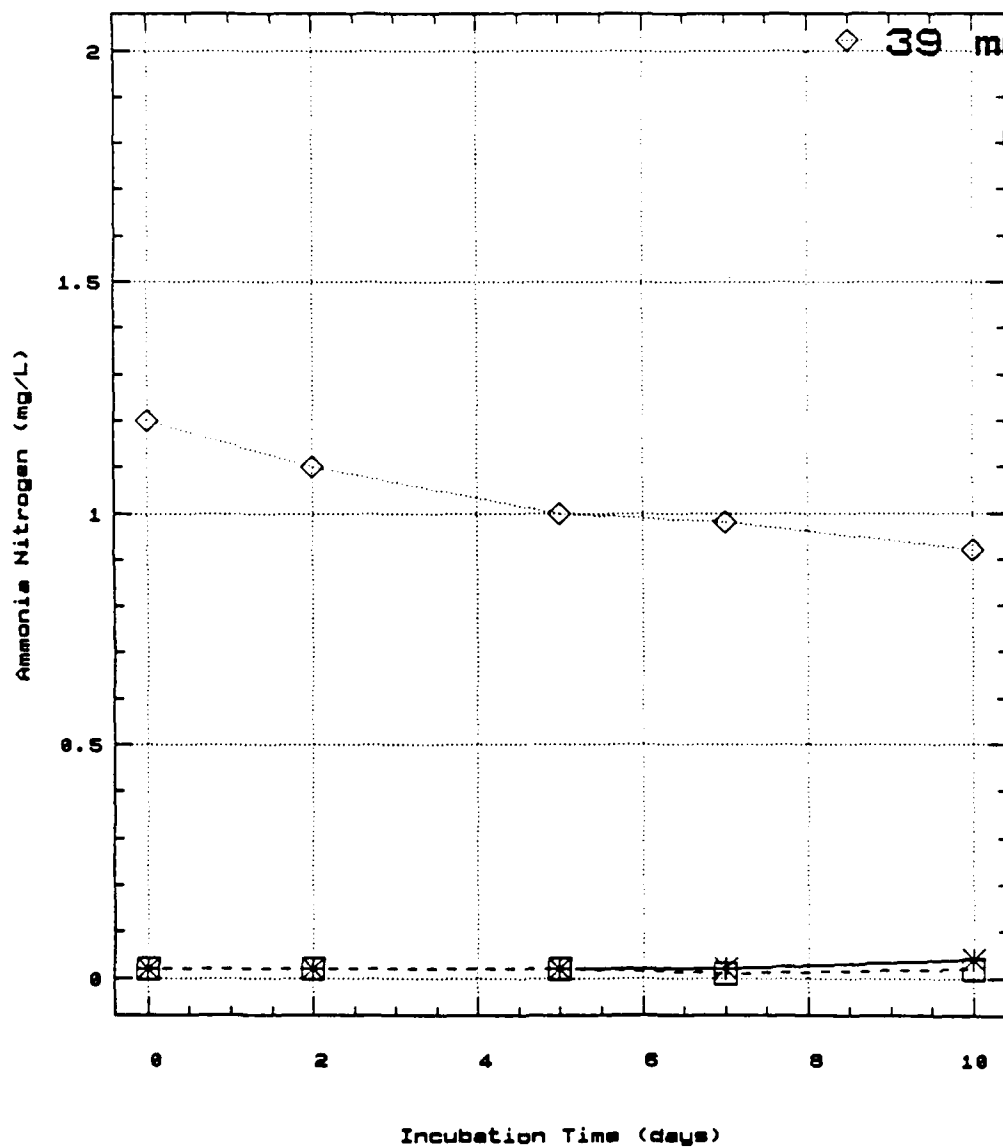
Figure C58. Lake Greeson, November 4, 1987.
10-day BOD, mean ammonia nitrogen

Figure C59. Lake Greeson, November 4, 1987.
10-day BOD, mean nitrate nitrogen
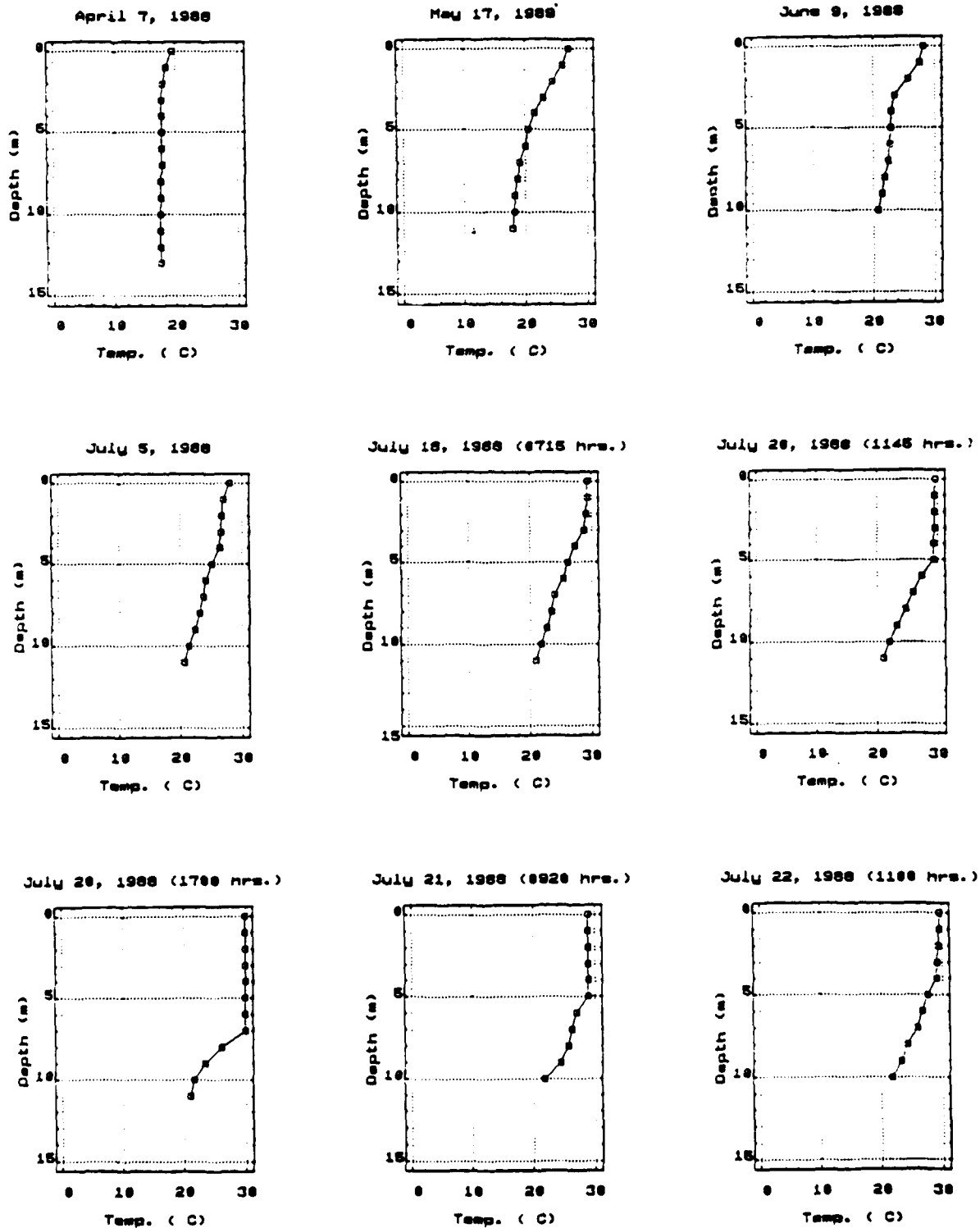
Figure C60.   Lake Nimrod temperature profiles
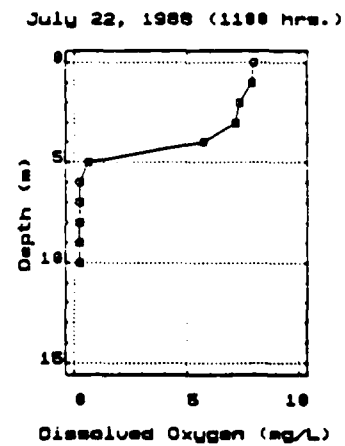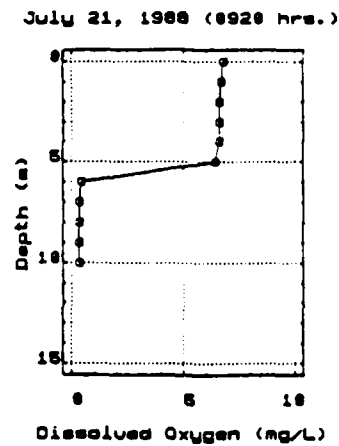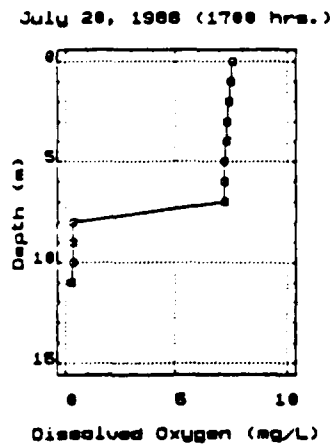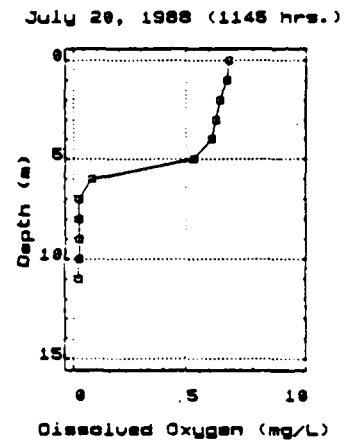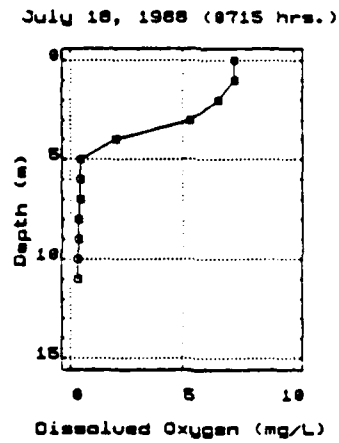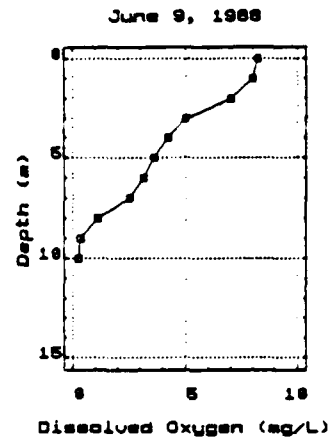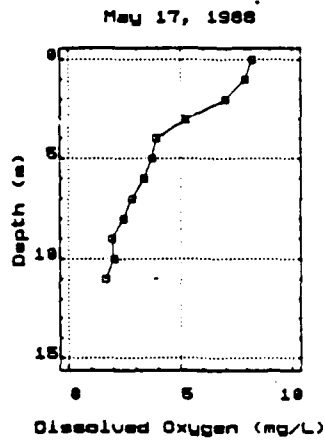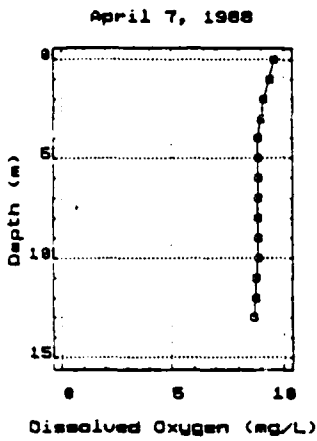
Figure C61.   Lake Nimrod, DO profiles

C61

NIMROD TAILWATER
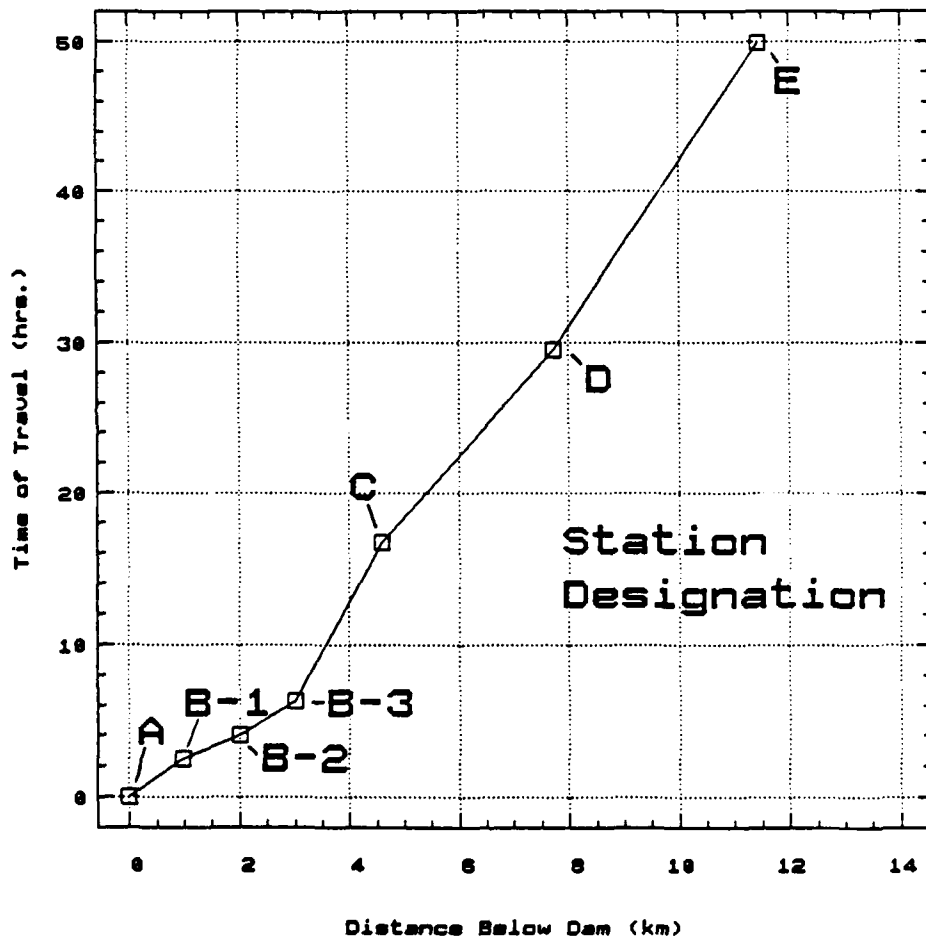
July 1988

Figure C62. Lake Nimrod tailwater, time
of travel versus distance below dam on
7/20/88-7/22/88

NIMROD TAILWATER
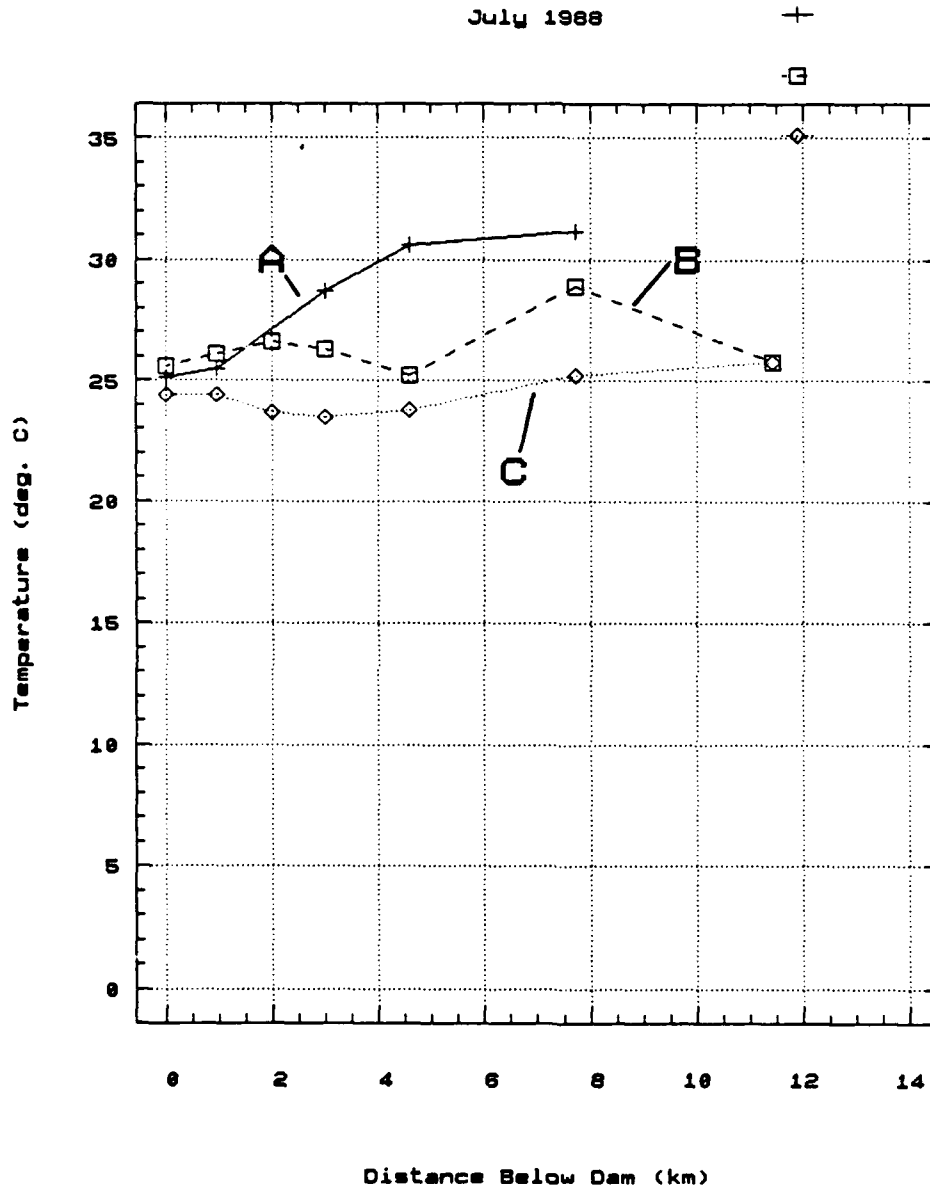
Figure C63. Lake Nimrod tailwater, tempera-
ture versus distance below dam on 7/20/88-
7/22/88 (A = low flow, steady state; B =
high flow, time of travel; C = high flow,
steady state)
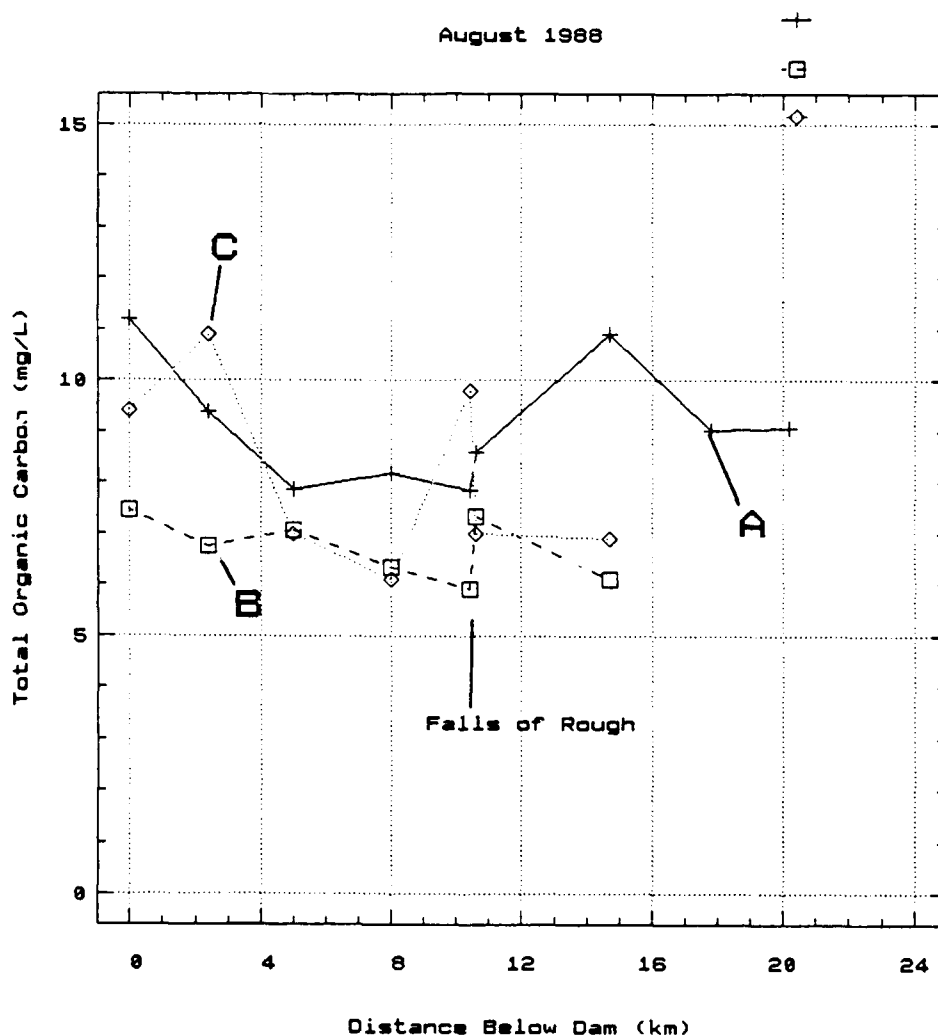
NIMROD TAILWATER
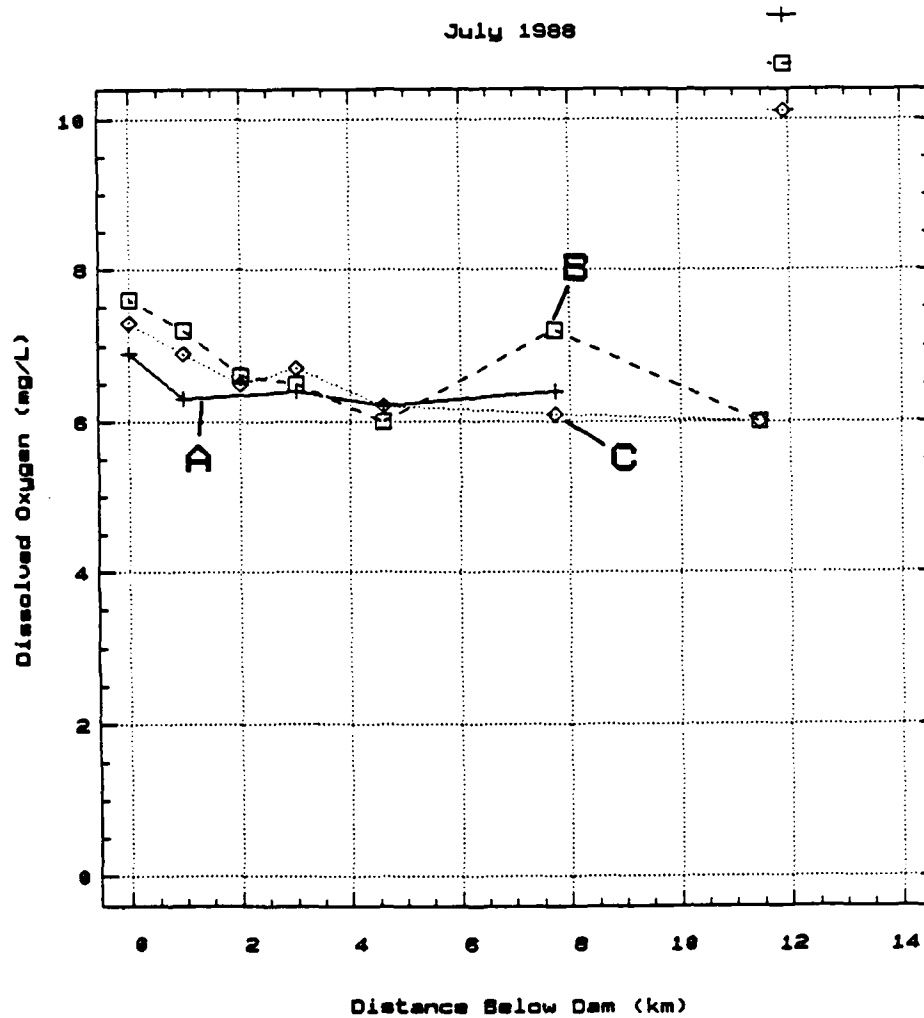
July 1988

Figure C64. Lake Nimrod tailwater, DO versus distance below dam on 7/20/88-7/22/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)

NIMROD TAILWATER
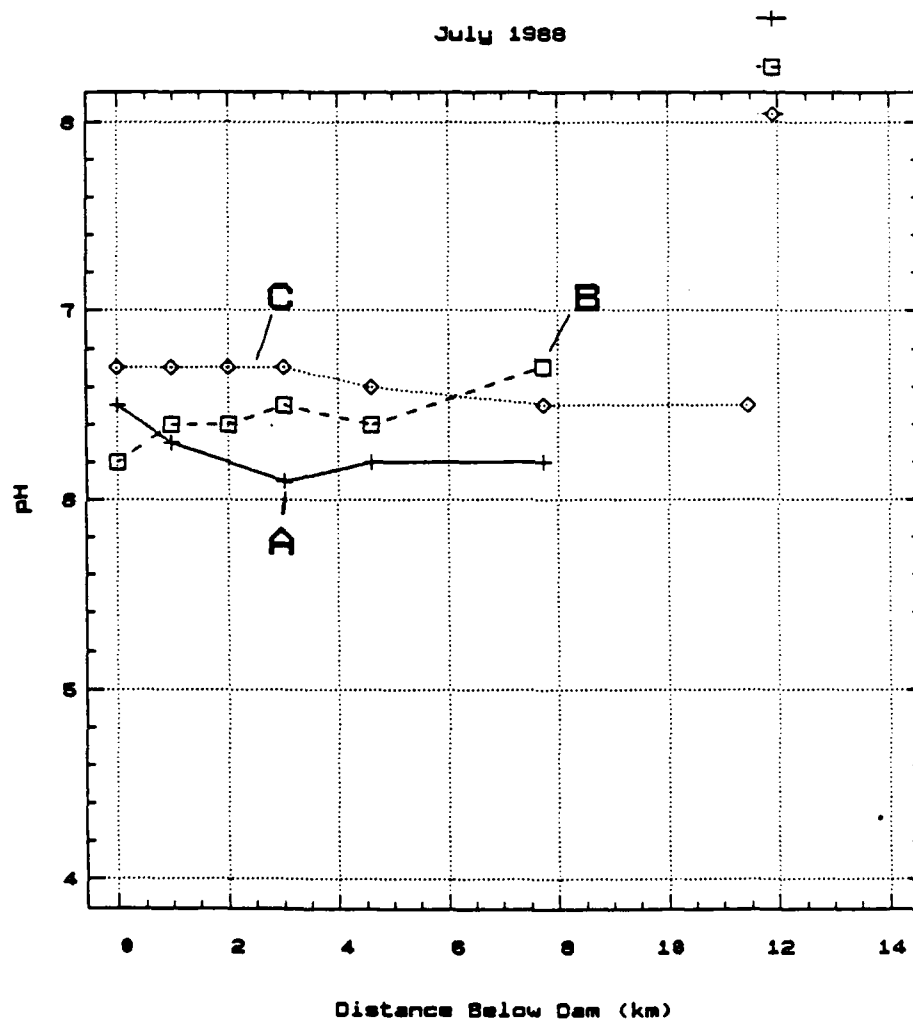
July 1988

Figure C65. Lake Nimrod tailwater, pH
versus distance below dam on 7/20/88-
7/22/88 (A = low flow, steady state;
B = high flow, time of travel; C =
    high flow, steady state)

NIMROD TAILWATER
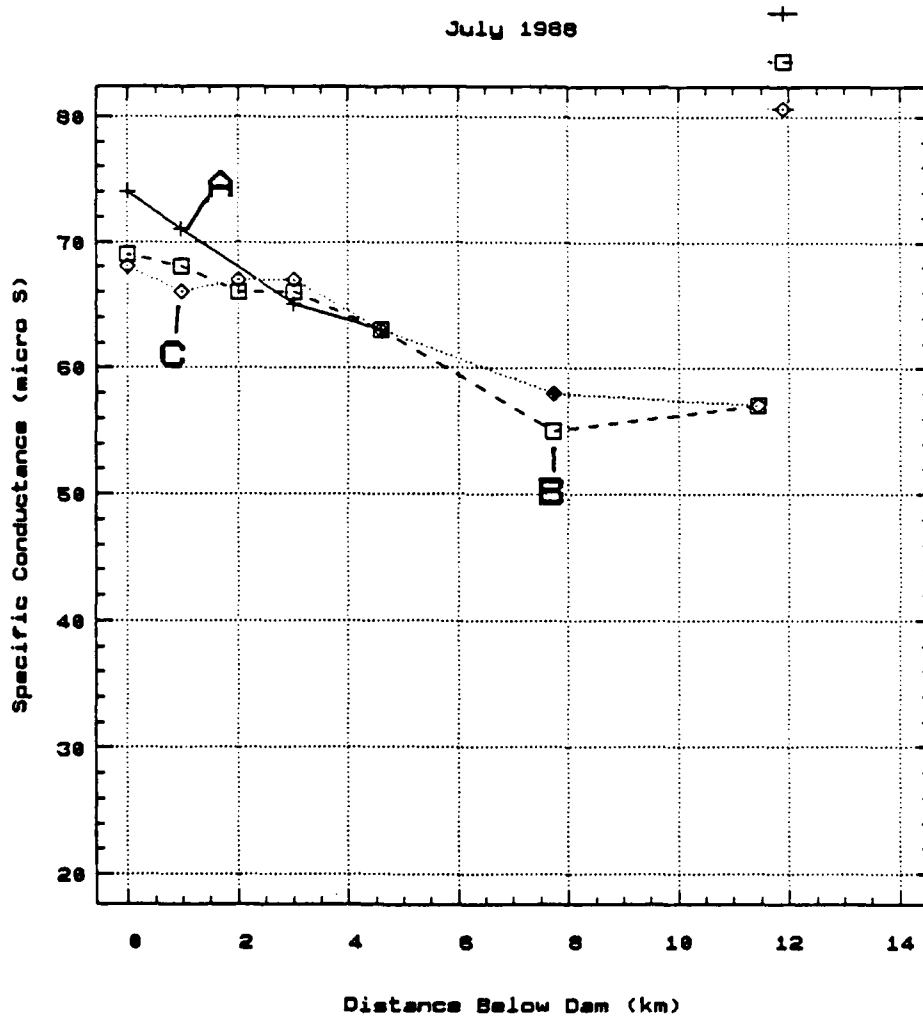
July 1988

Figure C66. Lake Nimrod tailwater, specific
conductance versus distance below dam on
7/20/88-7/22/88 (A = low flow, steady state;
B = high flow, time of travel; C = high flow,
steady state)

C66
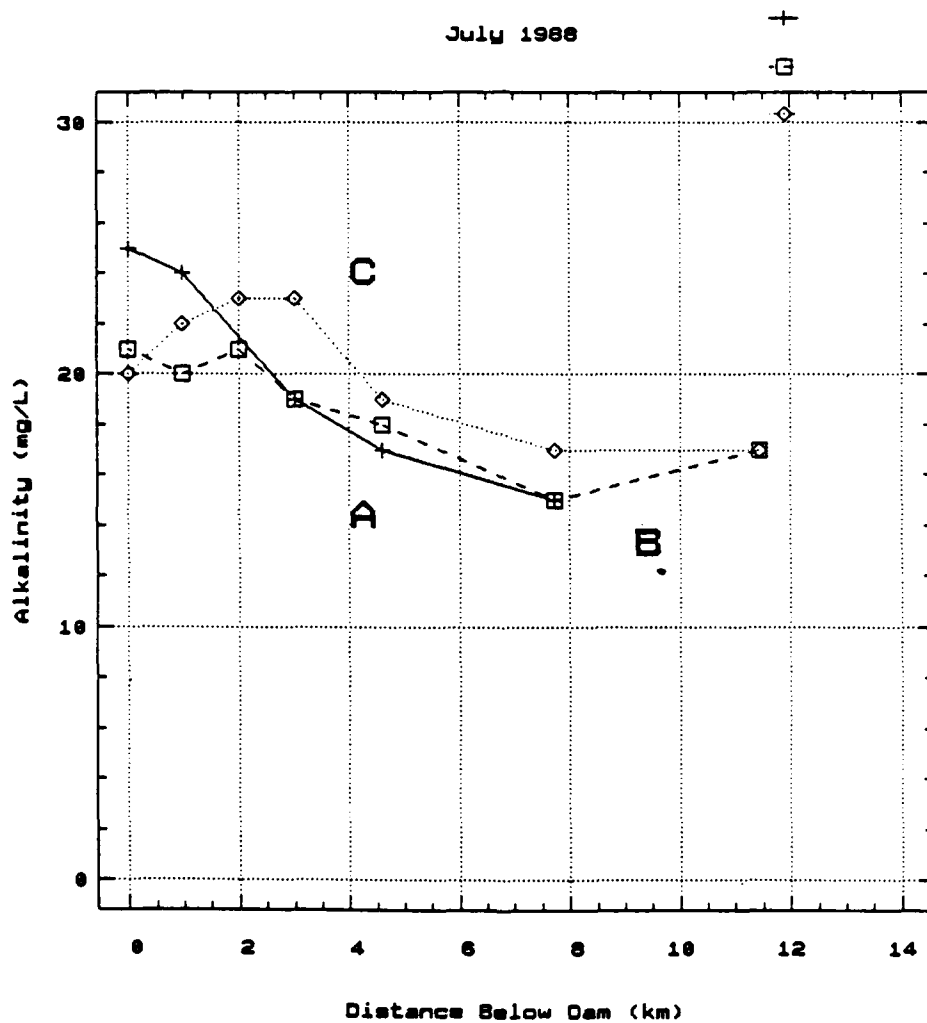
Figure C67. Lake Nimrod tailwater,
alkalinity versus distance below dam
on 7/20/88-7/22/88 (A = slow flow,
steady state; B = high flow, time of
travel; C = high flow, steady state)
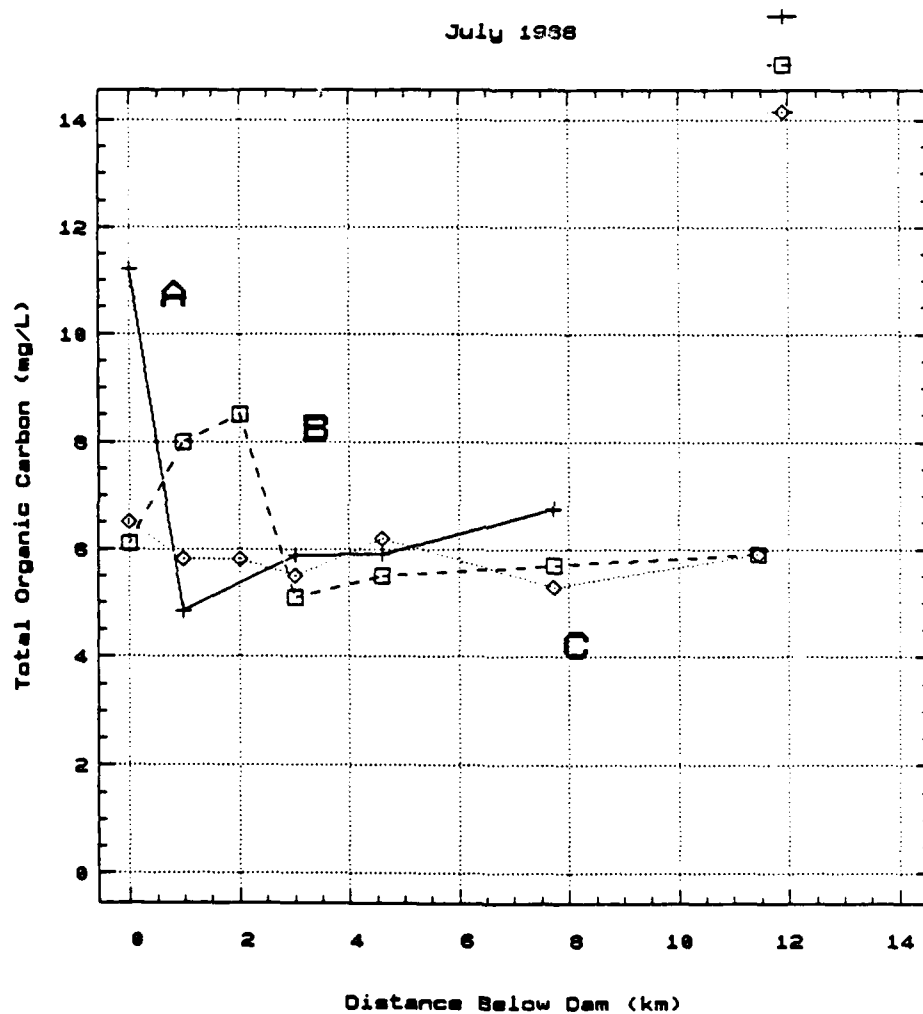
Figure C68. Lake Nimrod tailwater, total
organic carbon versus distance below dam
on 7/20/88-7/22/88 (A = low flow, steady
state; B = high flow, time of travel, C =
high flow, steady state)

NIMROD TAILWATER
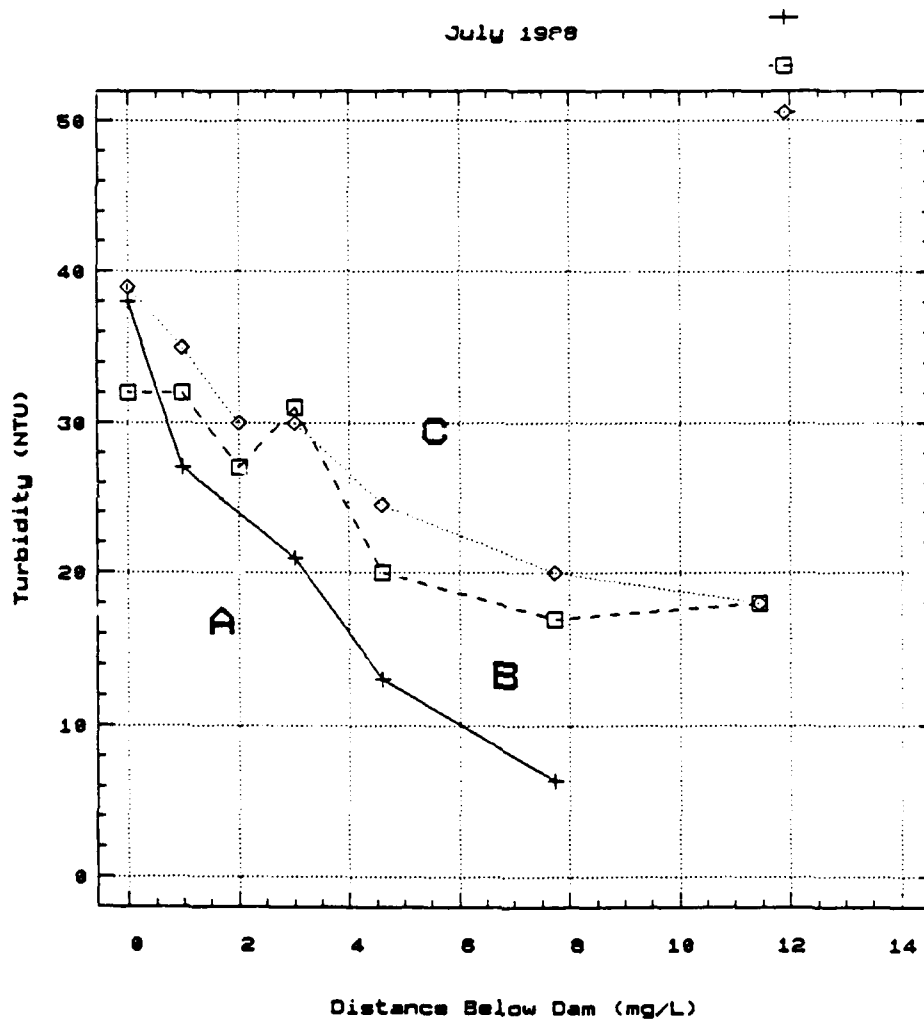
July 1988

Figure C69. Lake Nimrod tailwater,
turbidity versus distance below dam
on 7/20/88-7/22/88 (A = low flow,
steady state; B = high flow, time of
travel; C = high flow, steady state)

NIMROD TAILWATER
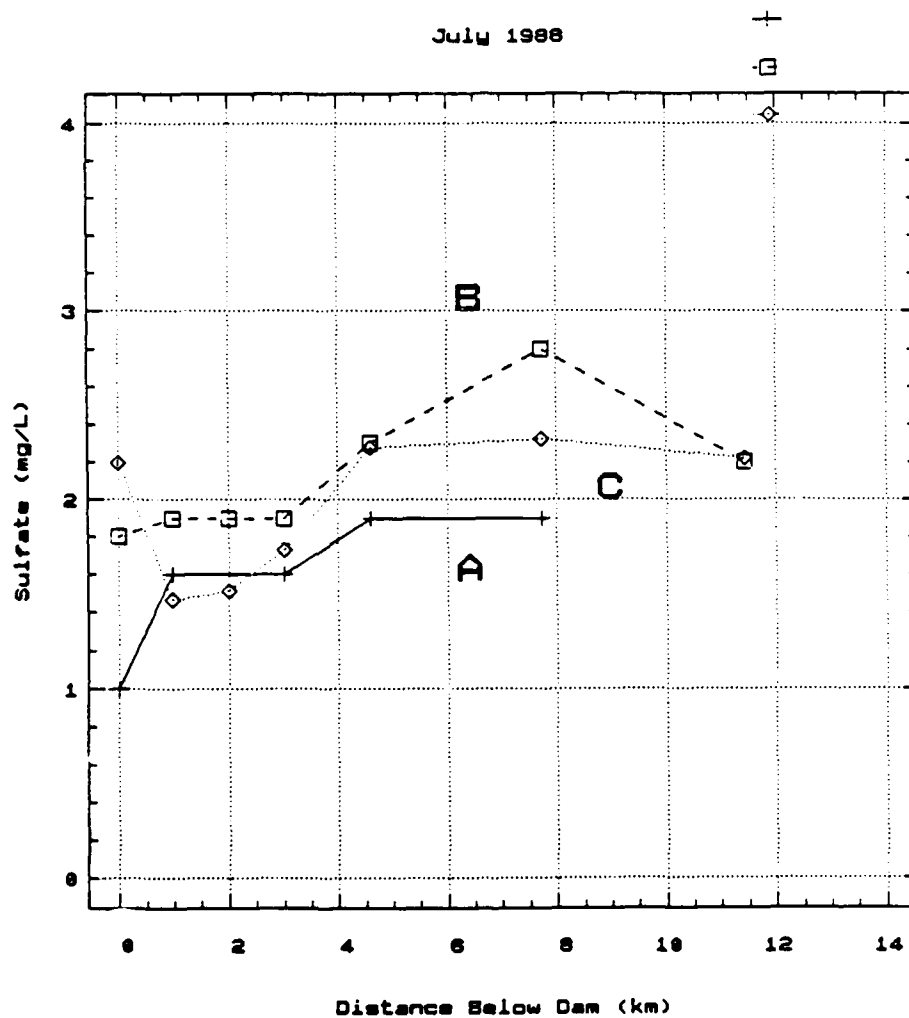
July 1988

Figure C70. Lake Nimrod tailwater, sulfate
versus distance below dam on 7/20/88-7/22/88
(A = low flow, steady state; B = high flow,
time of travel; C = high flow, steady state)
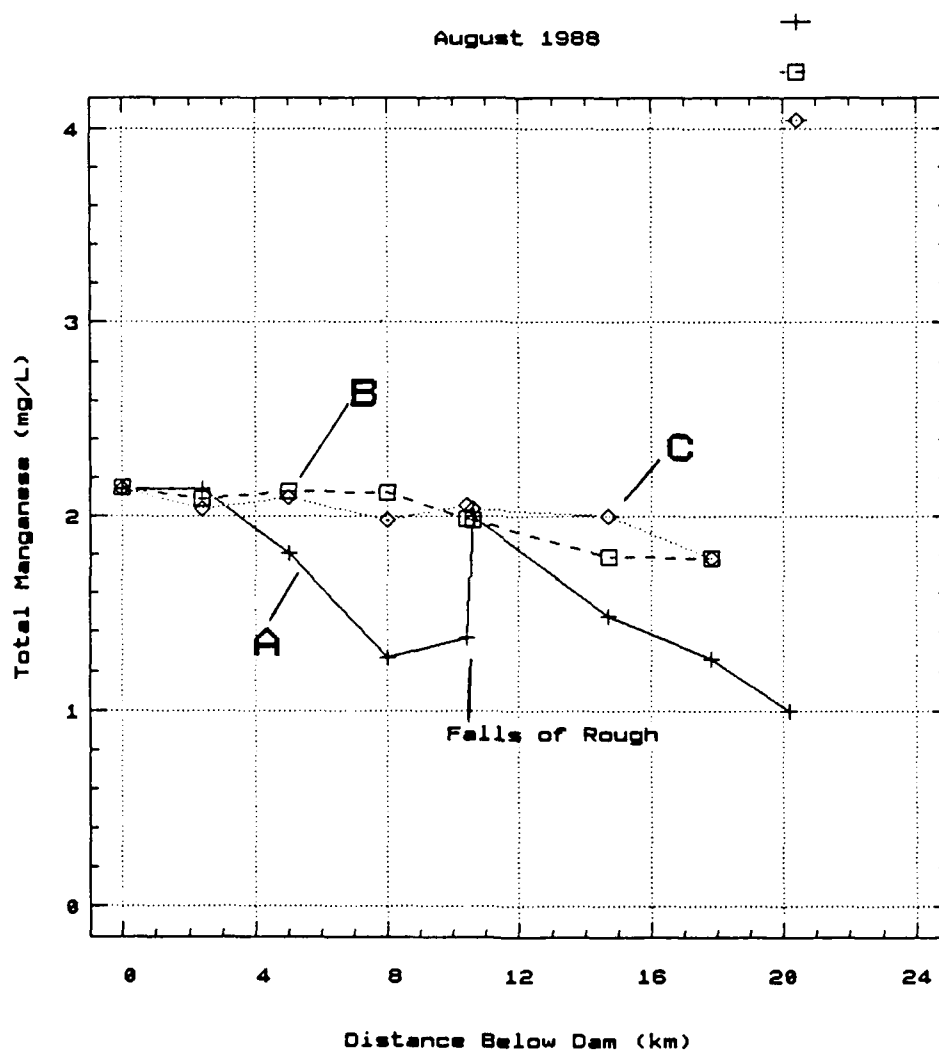
NIMROD TAILWATER
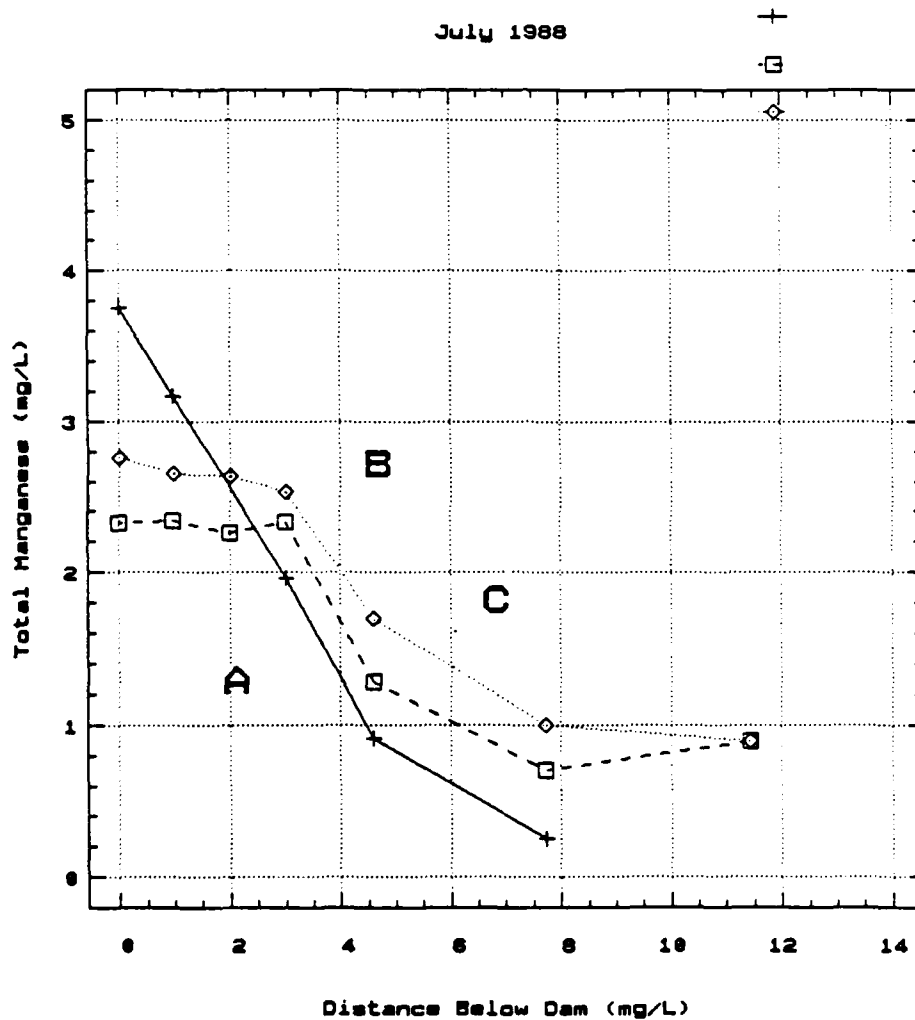
July 1988

Figure C71. Lake Nimrod tailwater, total
manganese versus distance below dam on
7/20/88-7/22/88 (A = low flow, steady
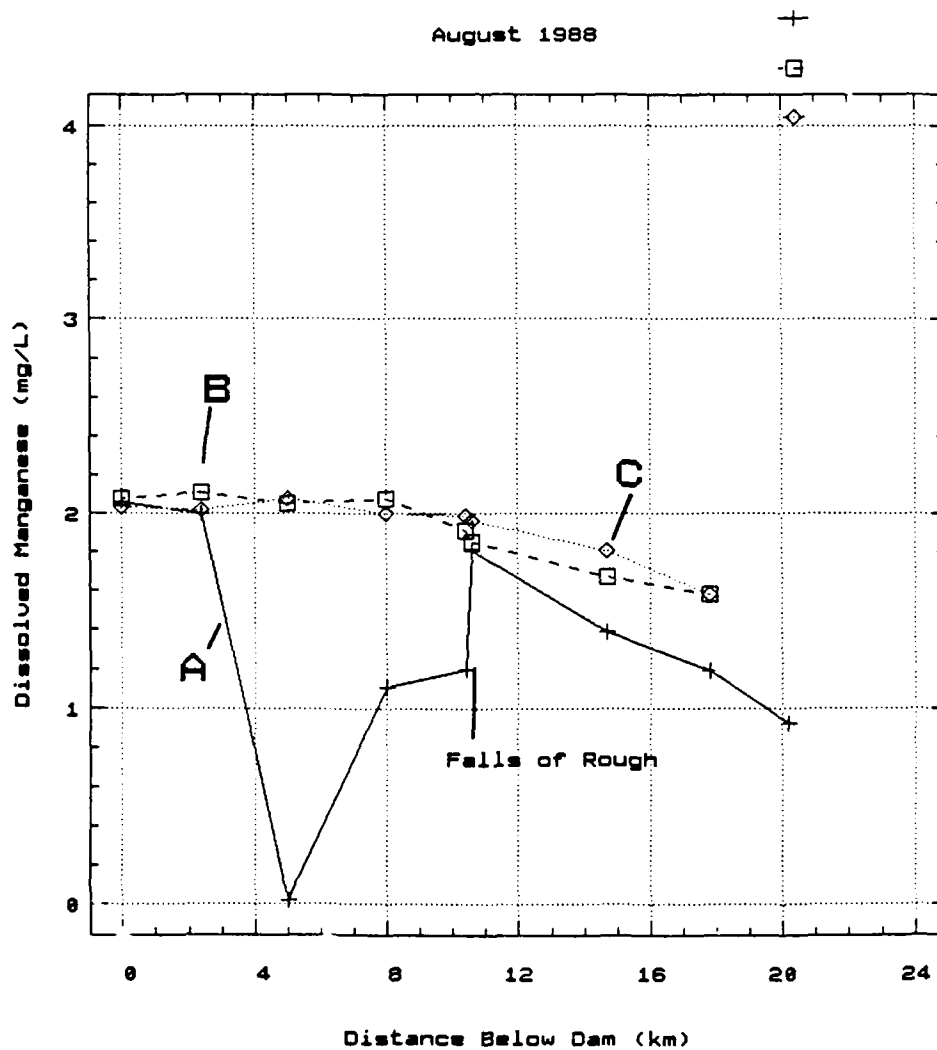state; B = high flow, time of travel;
C = high flow, steady state)
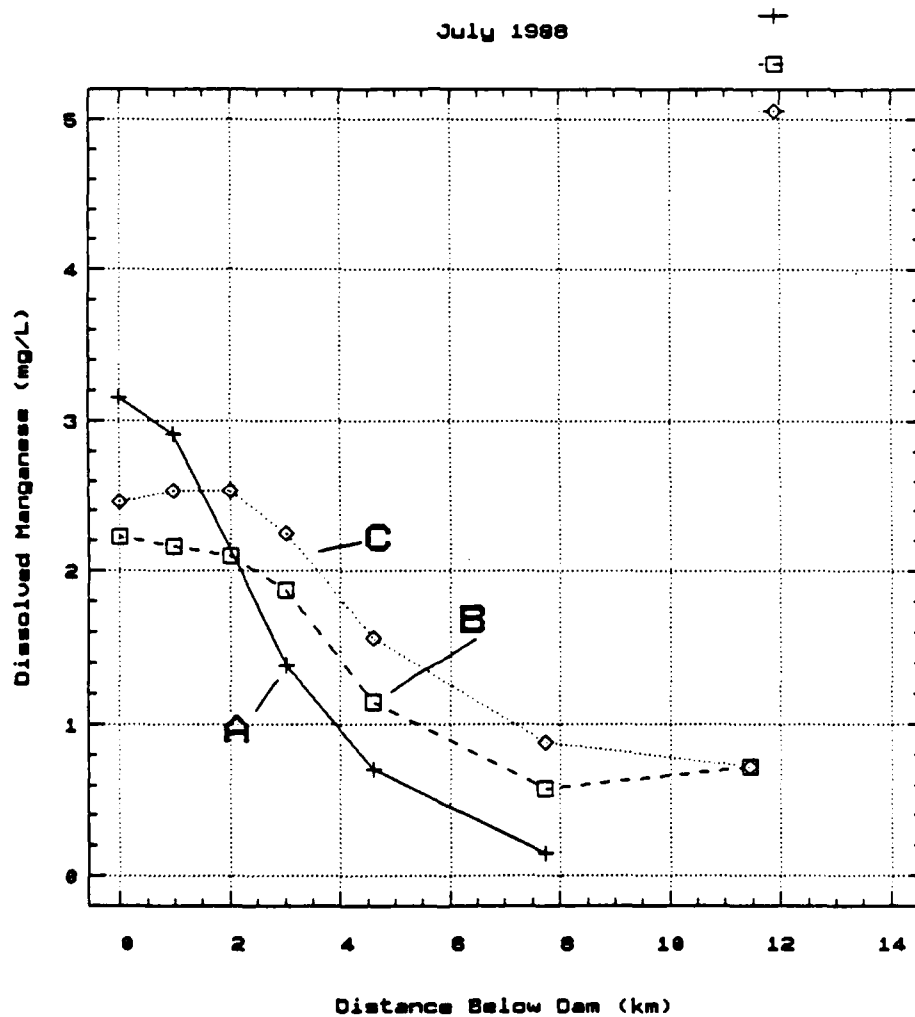
Figure C72. Lake Nimrod tailwater, dis-
solved manganese versus distance below
dam on 7/20/88-7/22/88 (A = low flow,
steady state; B = high flow, time of
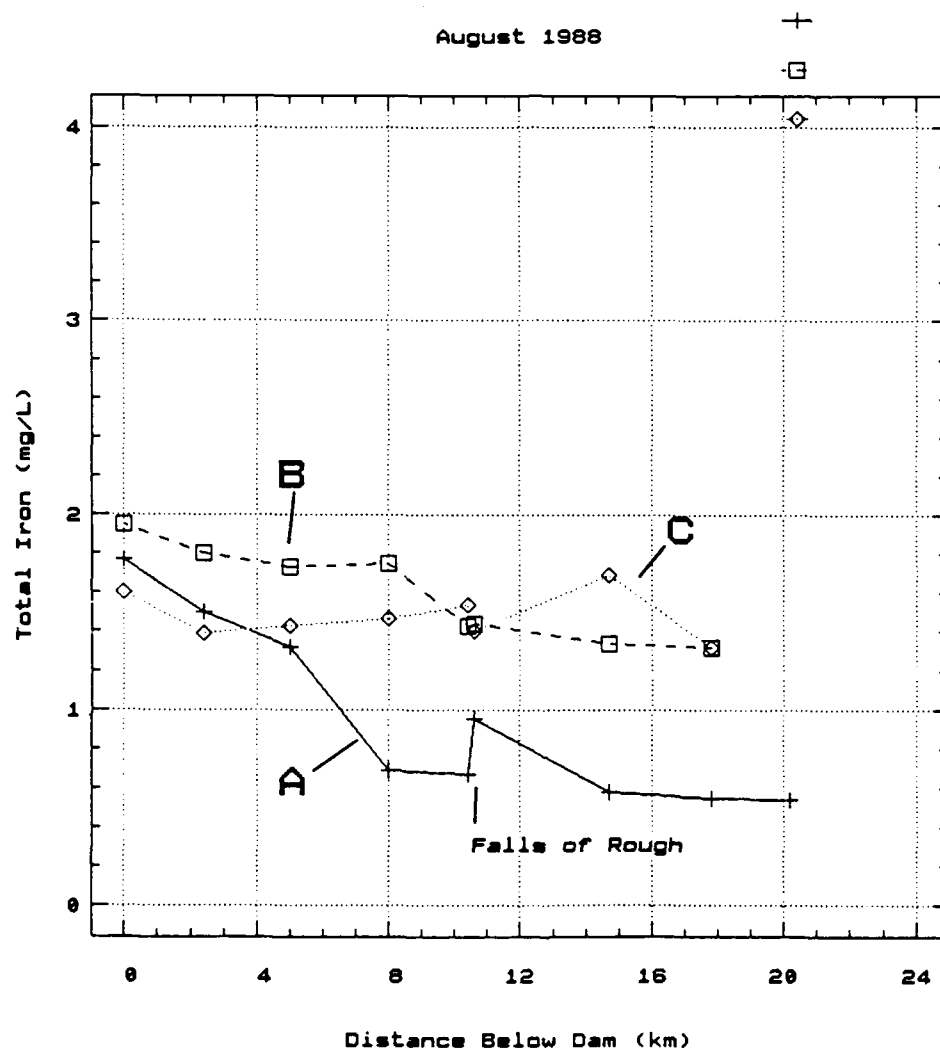 travel; C = high flow, steady state)
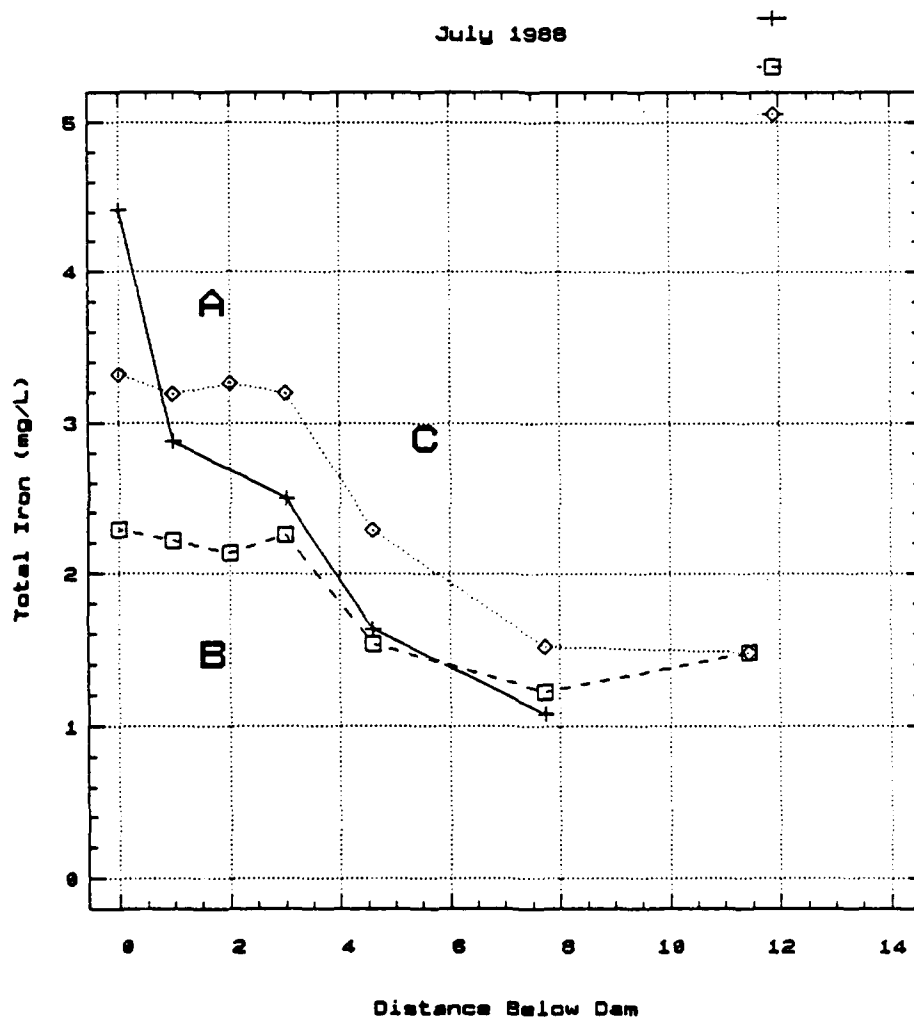
Figure C73. Lake Nimrod tailwater, total
iron versus distance below dam on 7/20/88-
7/22/88 (A = low flow, steady state; B =
high flow, time of travel, C = high flow,
steady state)
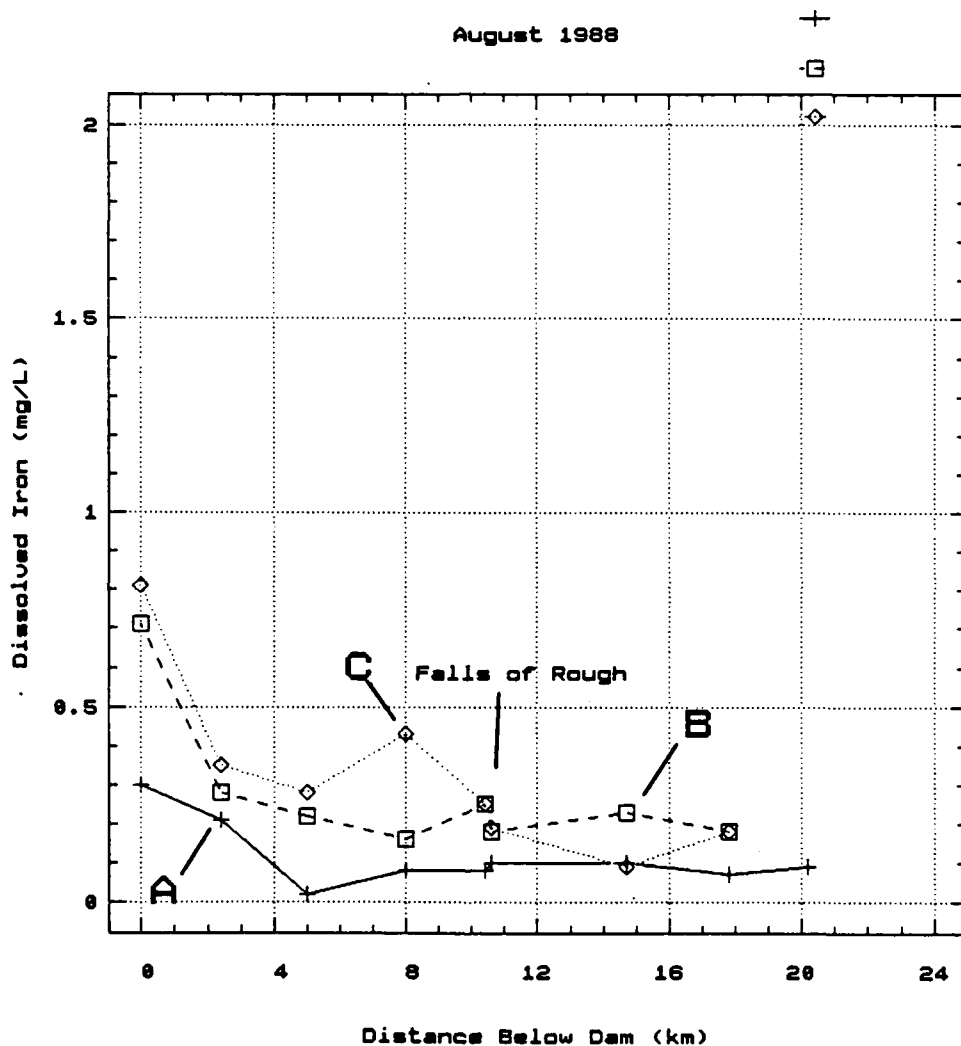
C73

NIMROD TAILWATER
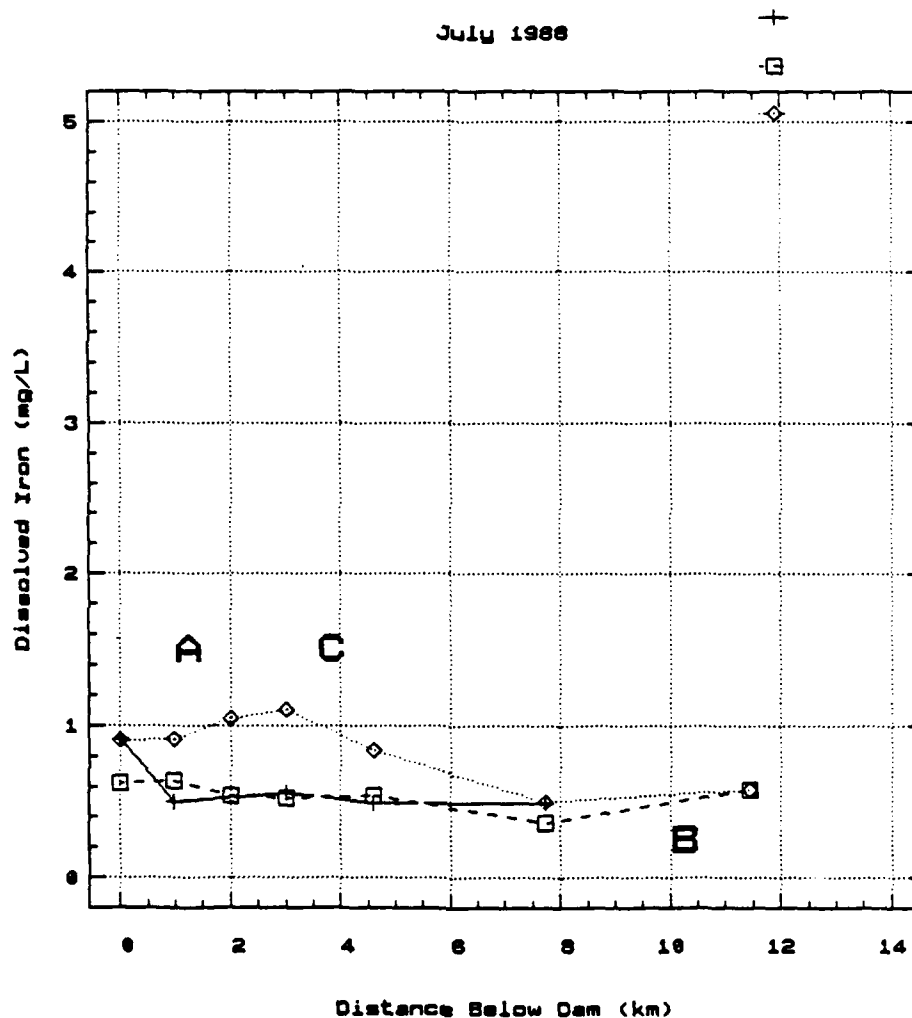
July 1988

Figure C74. Lake Nimrod tailwater, dis-
solved iron versus distance below dam on
7/20/88-7/22/88 (A = low flow, steady
state; B = high flow, time of travel;
C = high flow, steady state)

C74

NIMROD TAILWATER
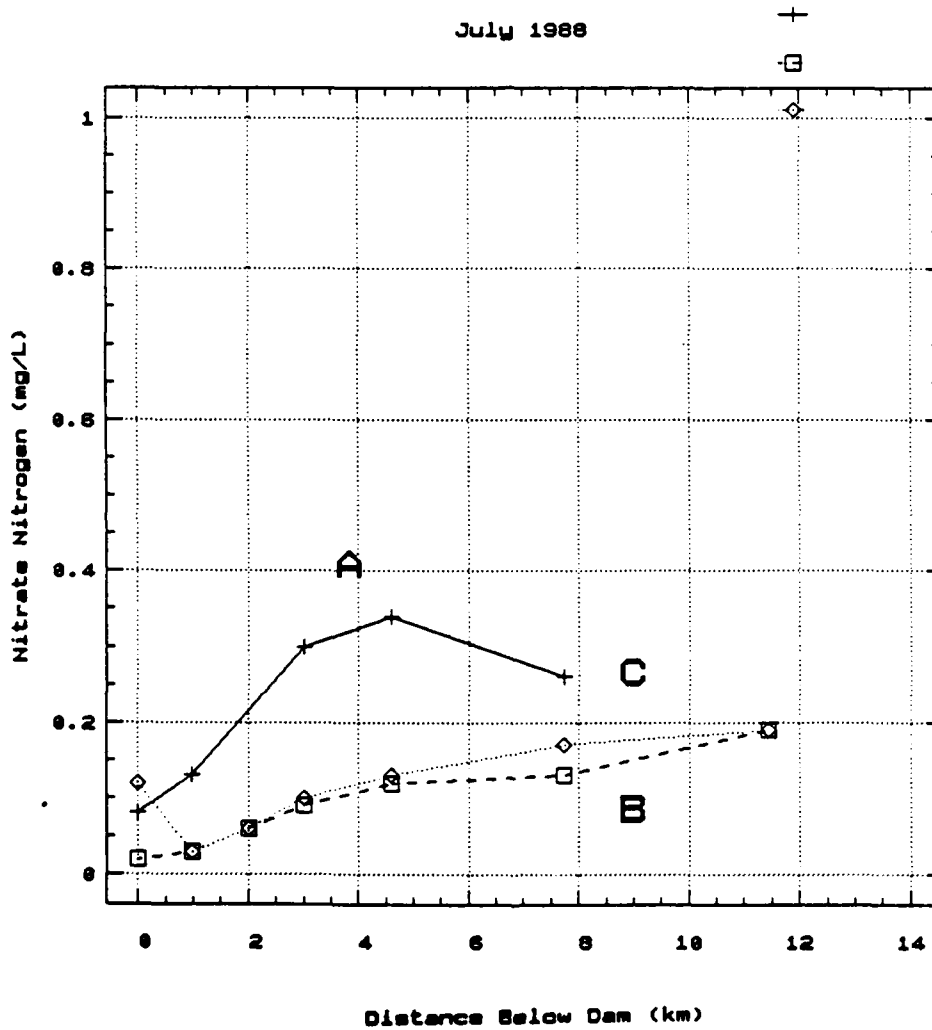
July 1988

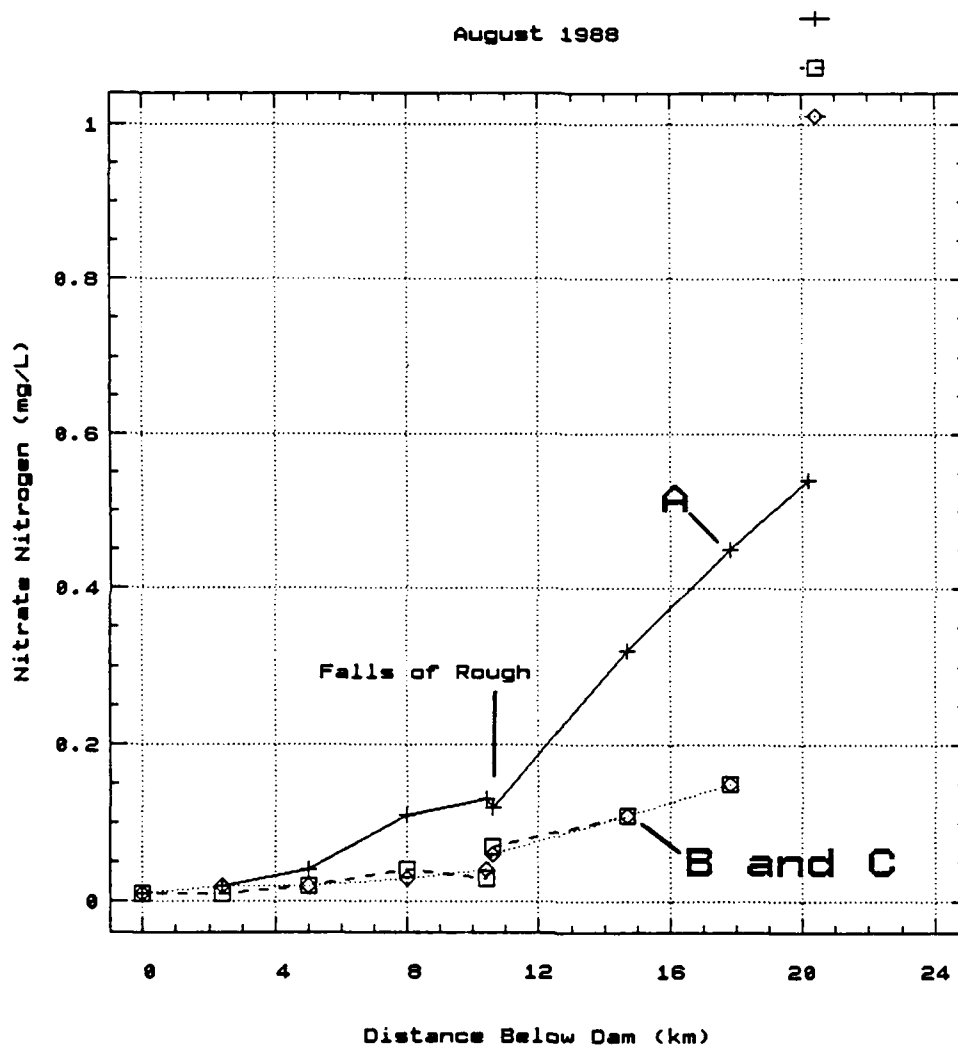

Figure C75. Lake Nimrod tailwater, nitrate
nitrogen versus distance below dam on
7/20/88-7/22/88 (A - low flow, steady
state; B = high flow, time of travel;
C = high flow, steady state)
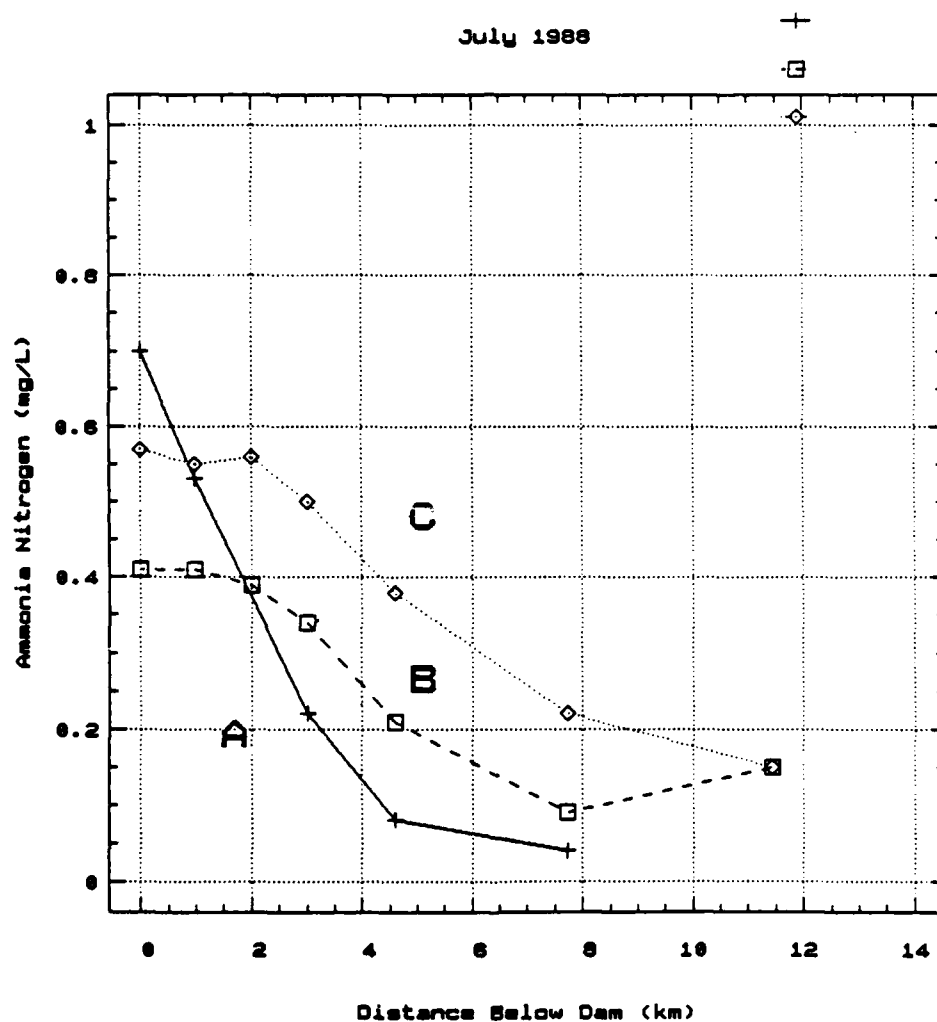
Figure C76. Lake Nimrod tailwater, ammonia
nitrogen versus distance below dam on
7/20/88-7/22/88 (A = low flow, steady
state, B = high flow, time of travel; C =
high flow, steady state)

LAKE NIMROD

10 Day BOD

* 2 m

□ 6 m

◇ 10 m
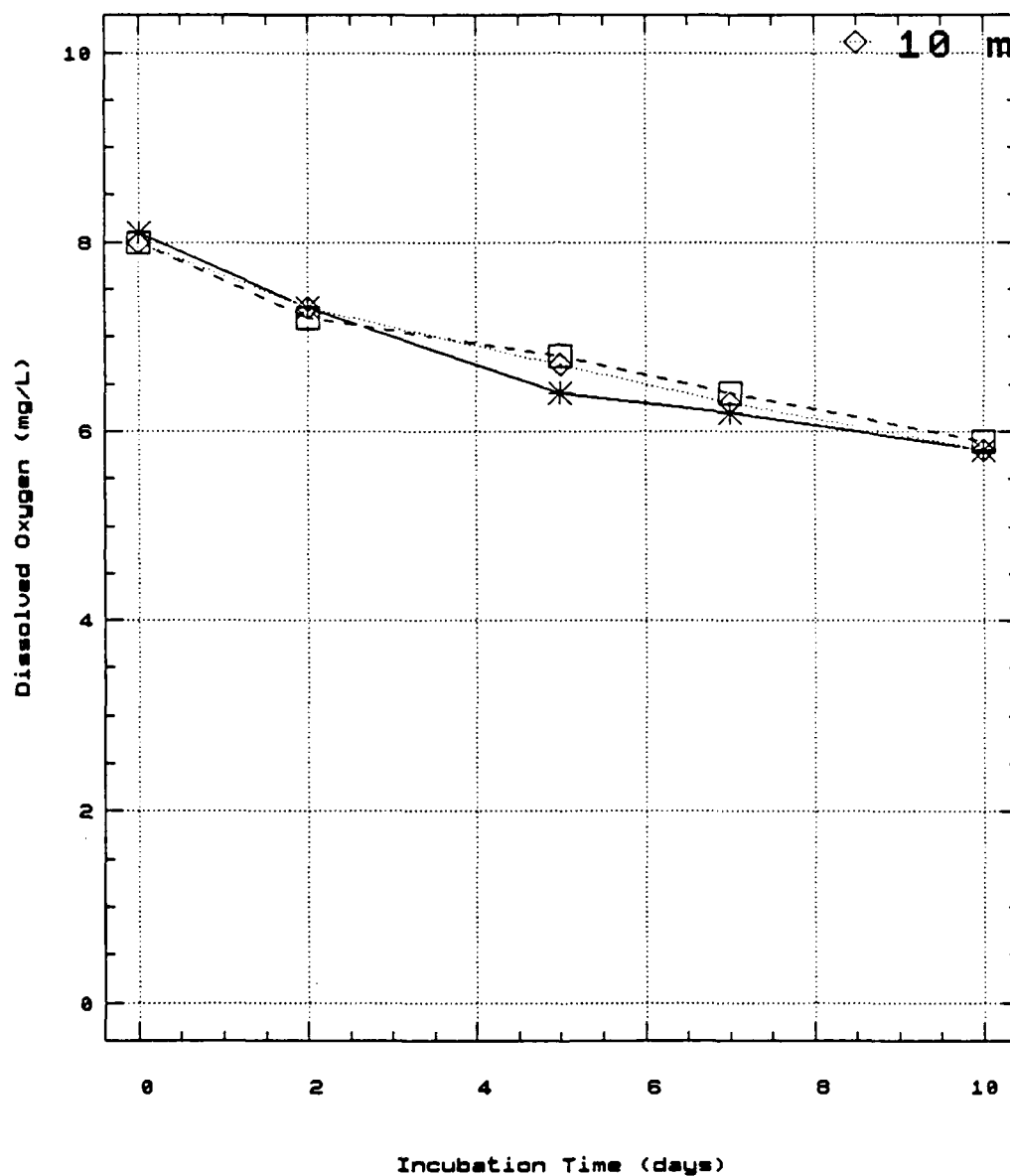
Figure 77.   Lake Nimrod, July 6, 1988,
10-day BOD, mean DO

LAKE NIMROD

10 Day BOD

* ✳ **2 m**
* ▣ **6 m**
* ◇ **10 m**
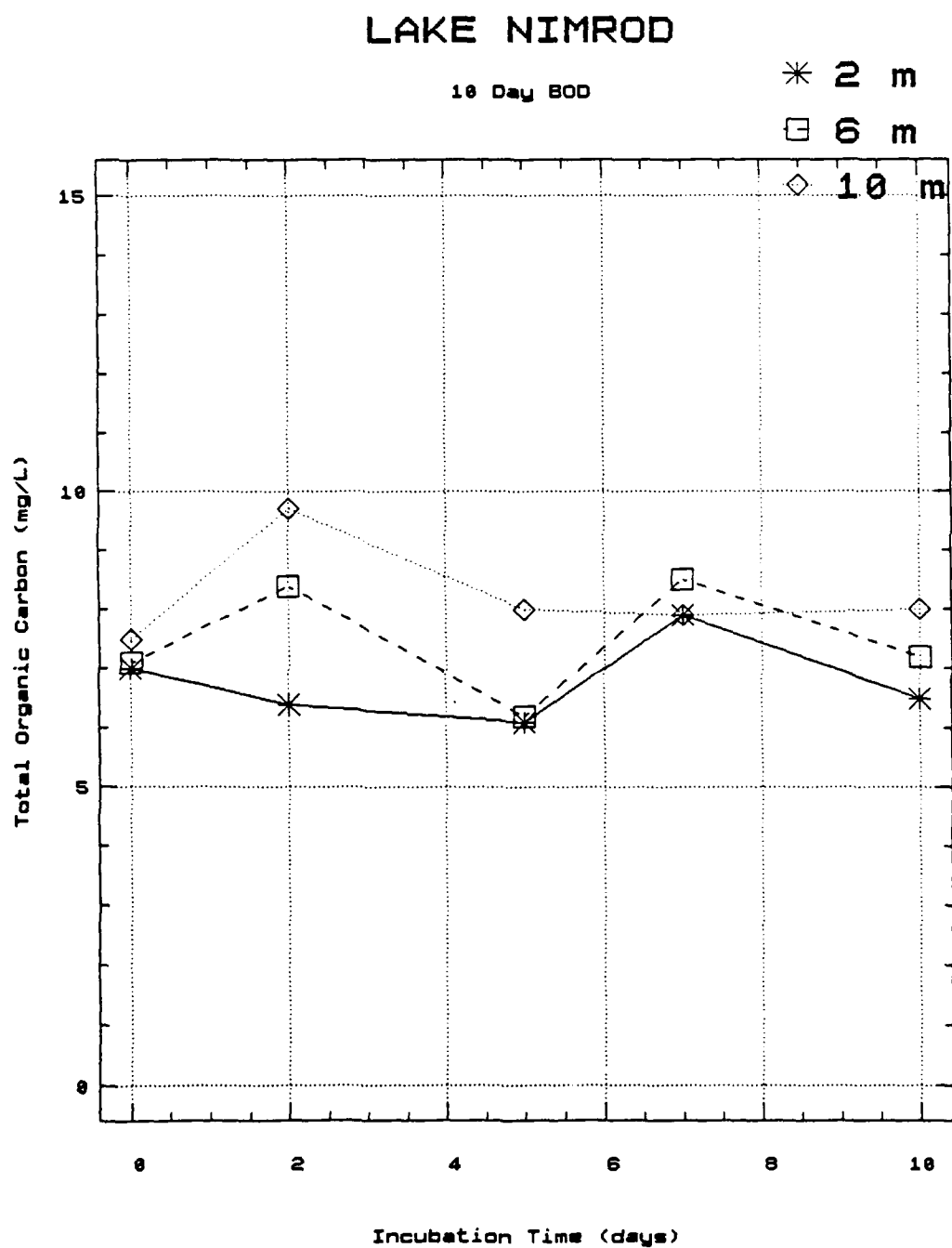
Figure 78. Lake Nimrod, July 6, 1988,
10-day BOD, mean total organic carbon

C78
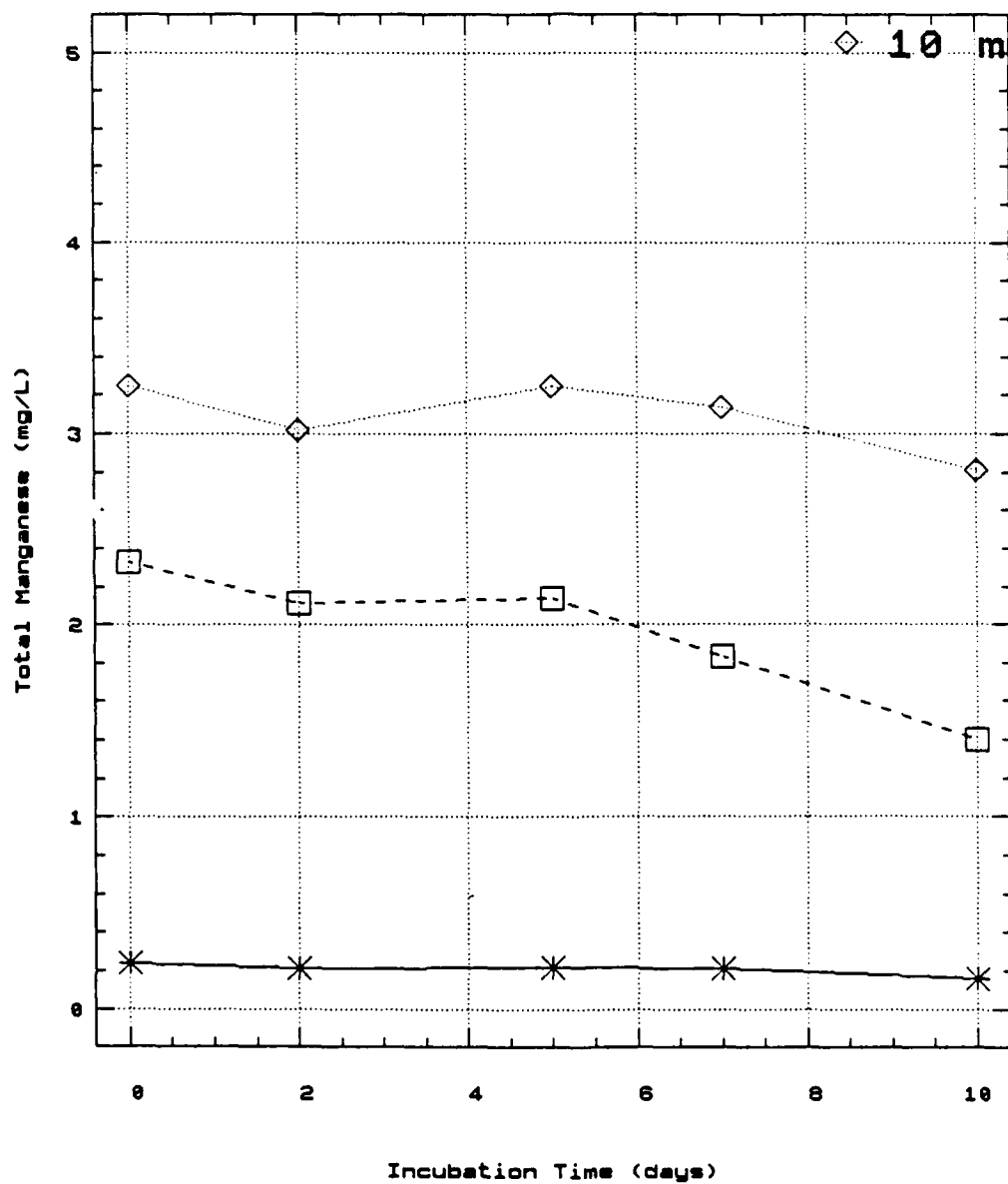
Figure C79. Lake Nimrod, July 6, 1988,
10-day BOD, mean total manganese
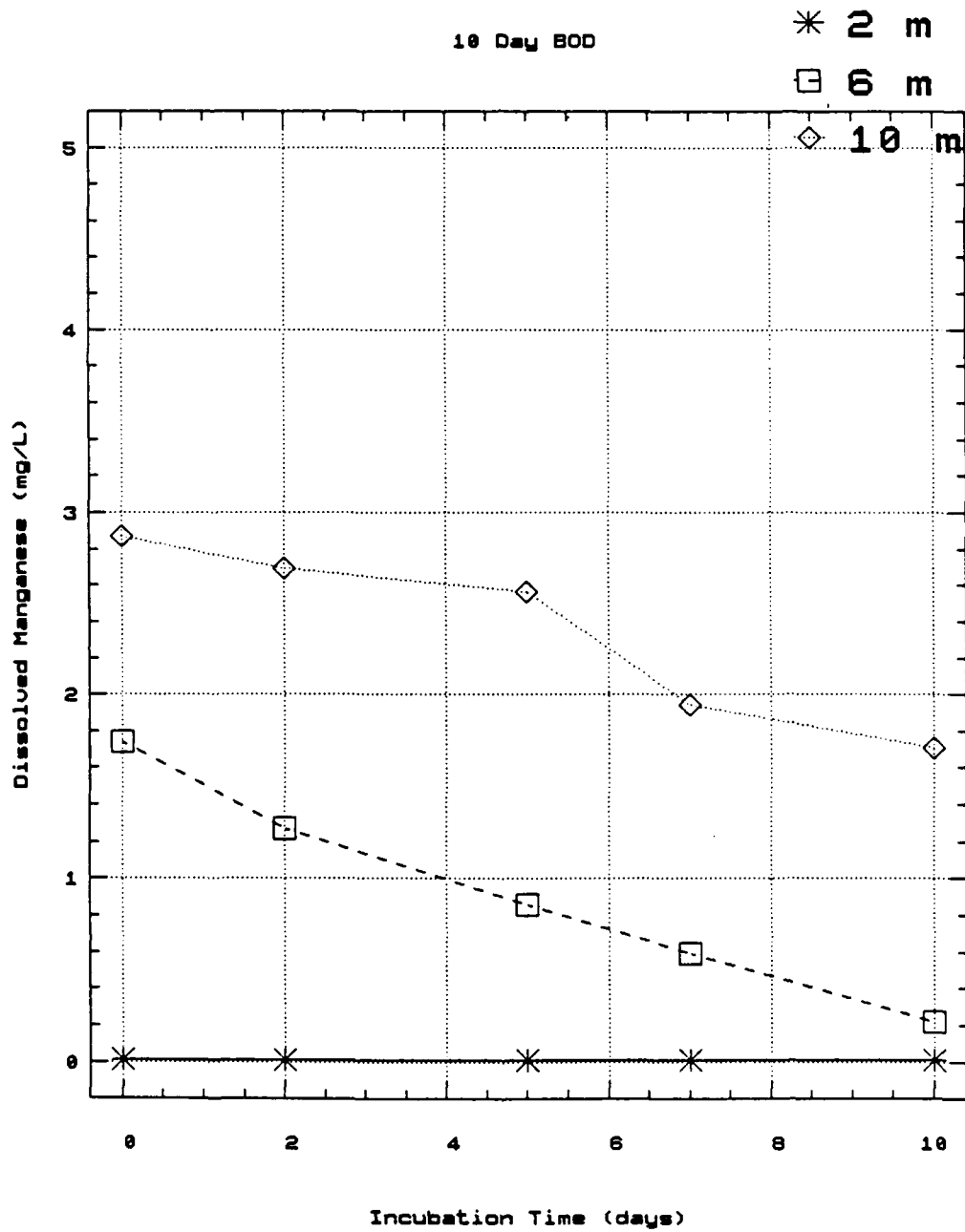
Figure 80. Lake Nimrod, July 6, 1988,
10-day BOD, mean dissolved manganese

LAKE NIMROD

10 Day BOD

✳ 2 m

⊟ 6 m

◇ 10 m

Total Iron (mg/L)

Incubation Time (days)
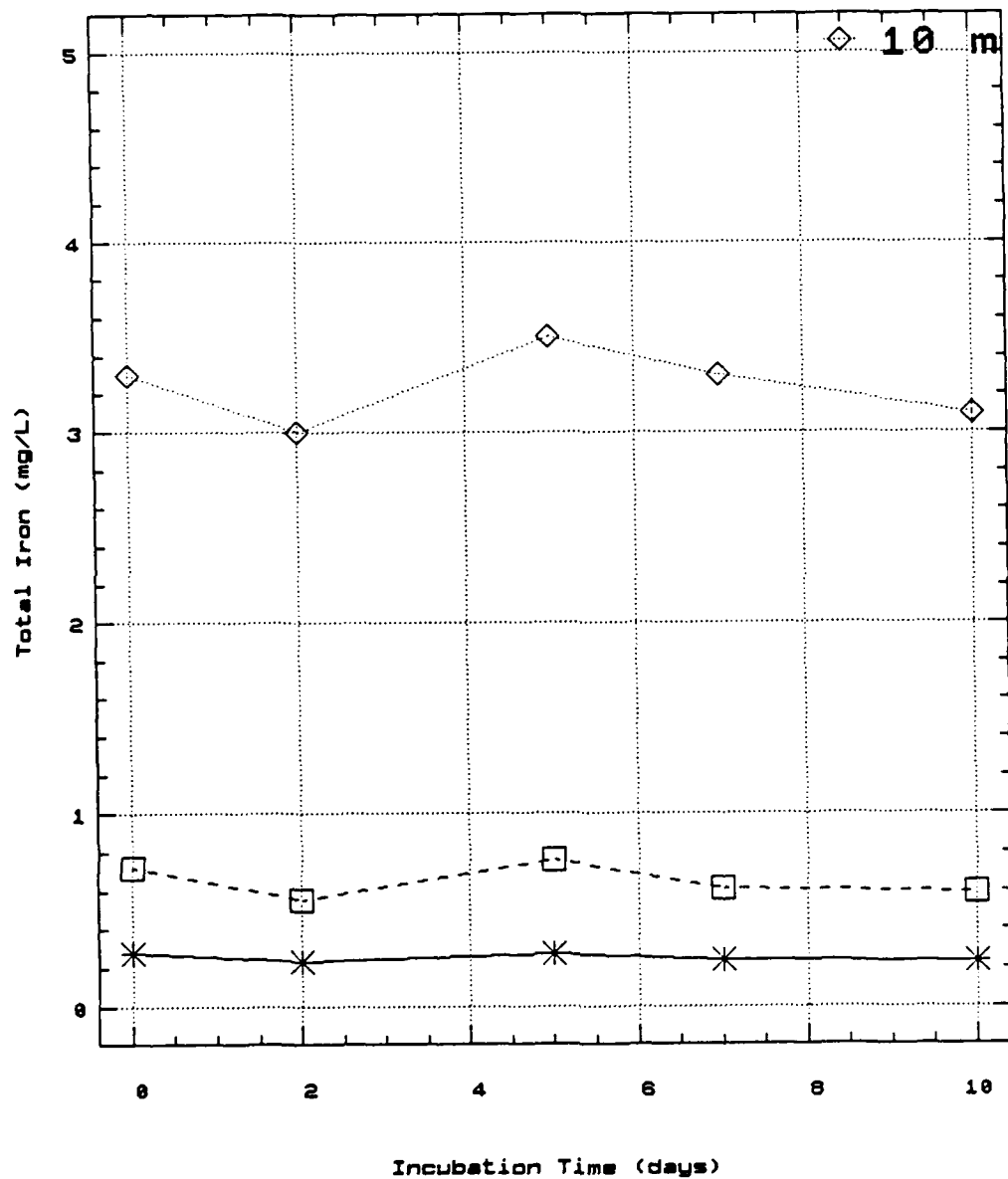
Figure 81. Lake Nimrod, July 6, 1988,
mean 10-day BOD, total iron

C81

LAKE NIMROD

10 Day BOD

✳ **2 m**

⊟ **6 m**

◇ **10 m**
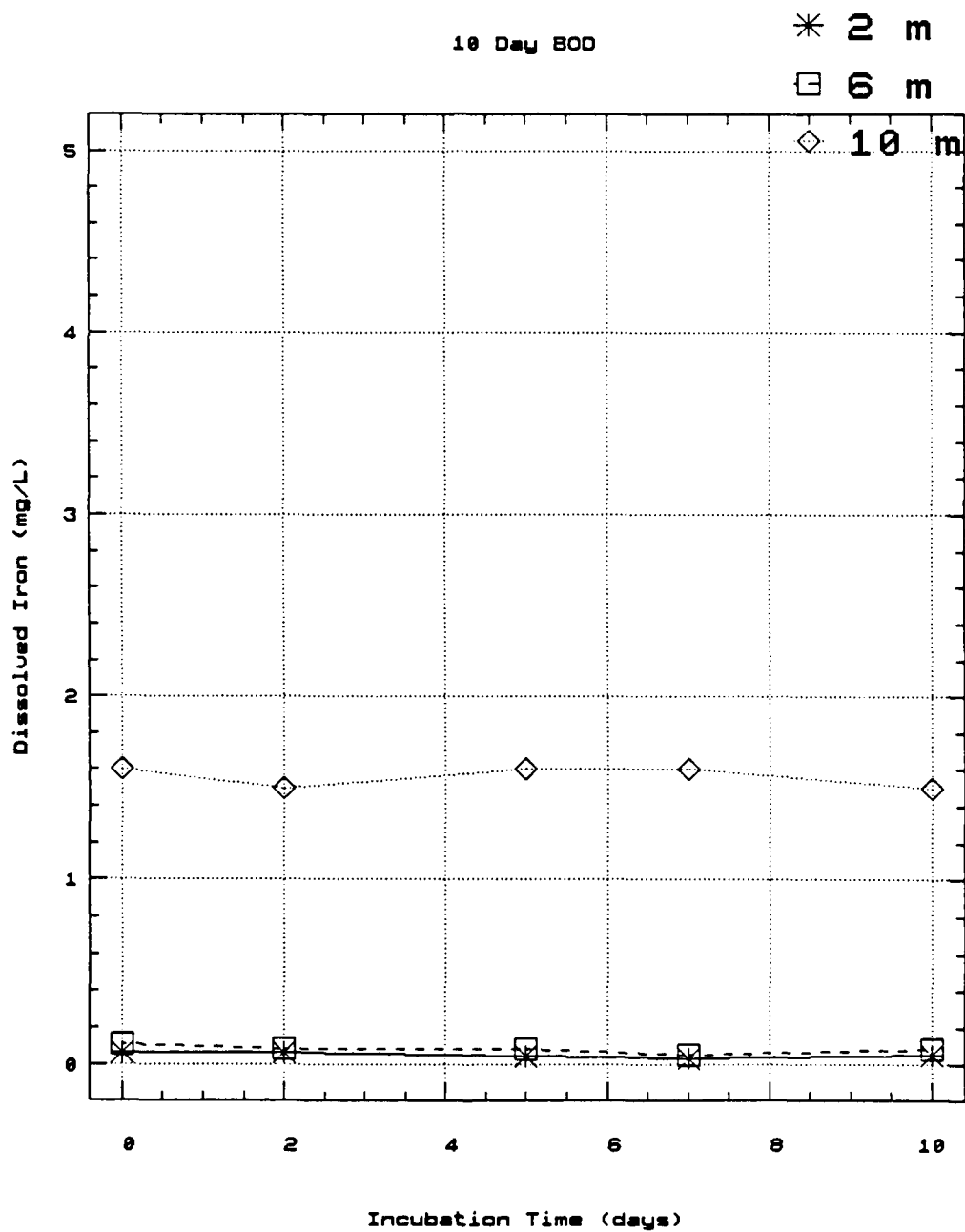
Figure 82. Lake Nimrod, July 6, 1988,
10-day BOD, mean dissolved iron
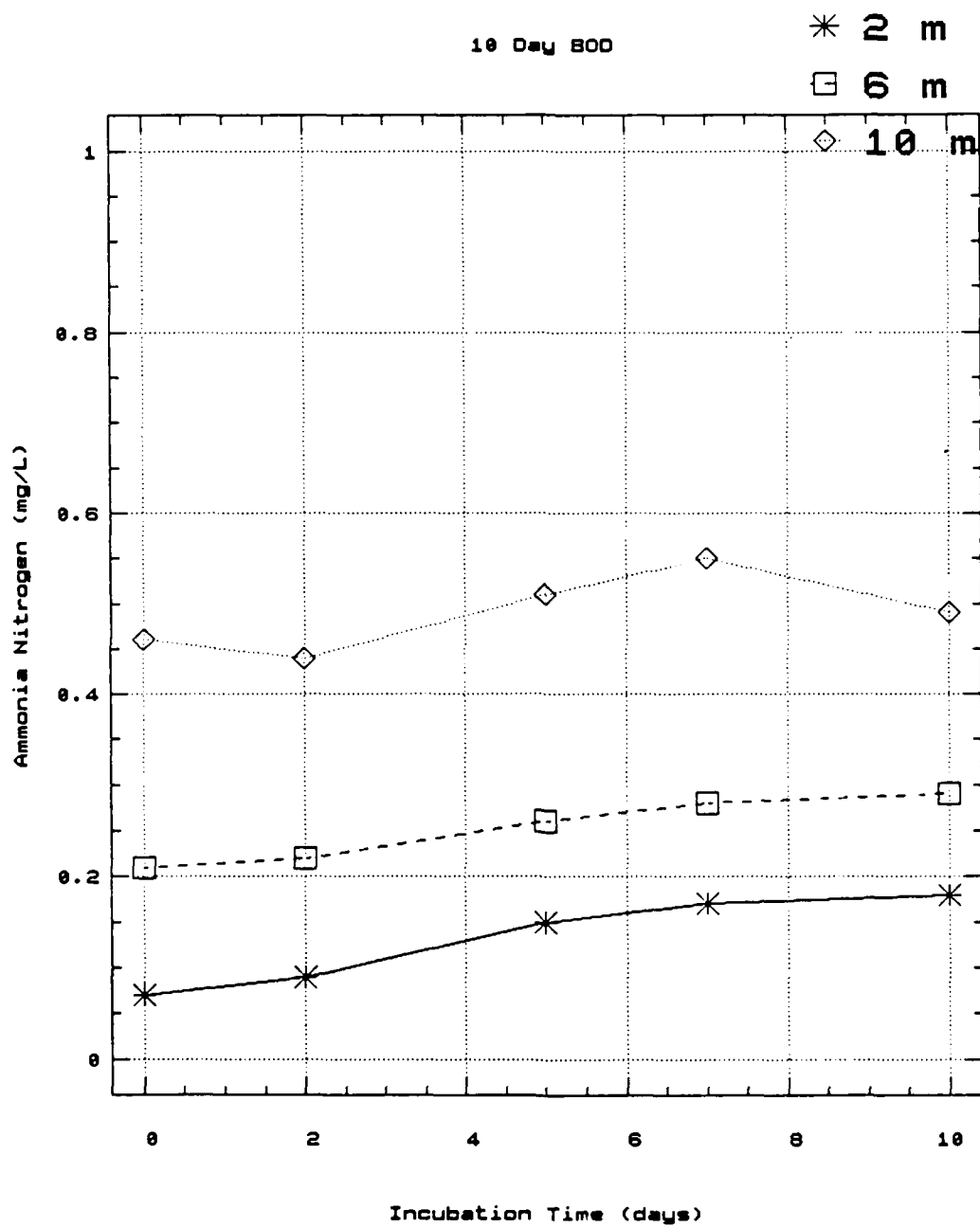
Figure 83. Lake Nimrod, July 6, 1988,
10-day BOD, mean ammonia nitrogen

LAKE NIMROD

10 Day BOD

* 2 m
□ 6 m
◇ 10 m
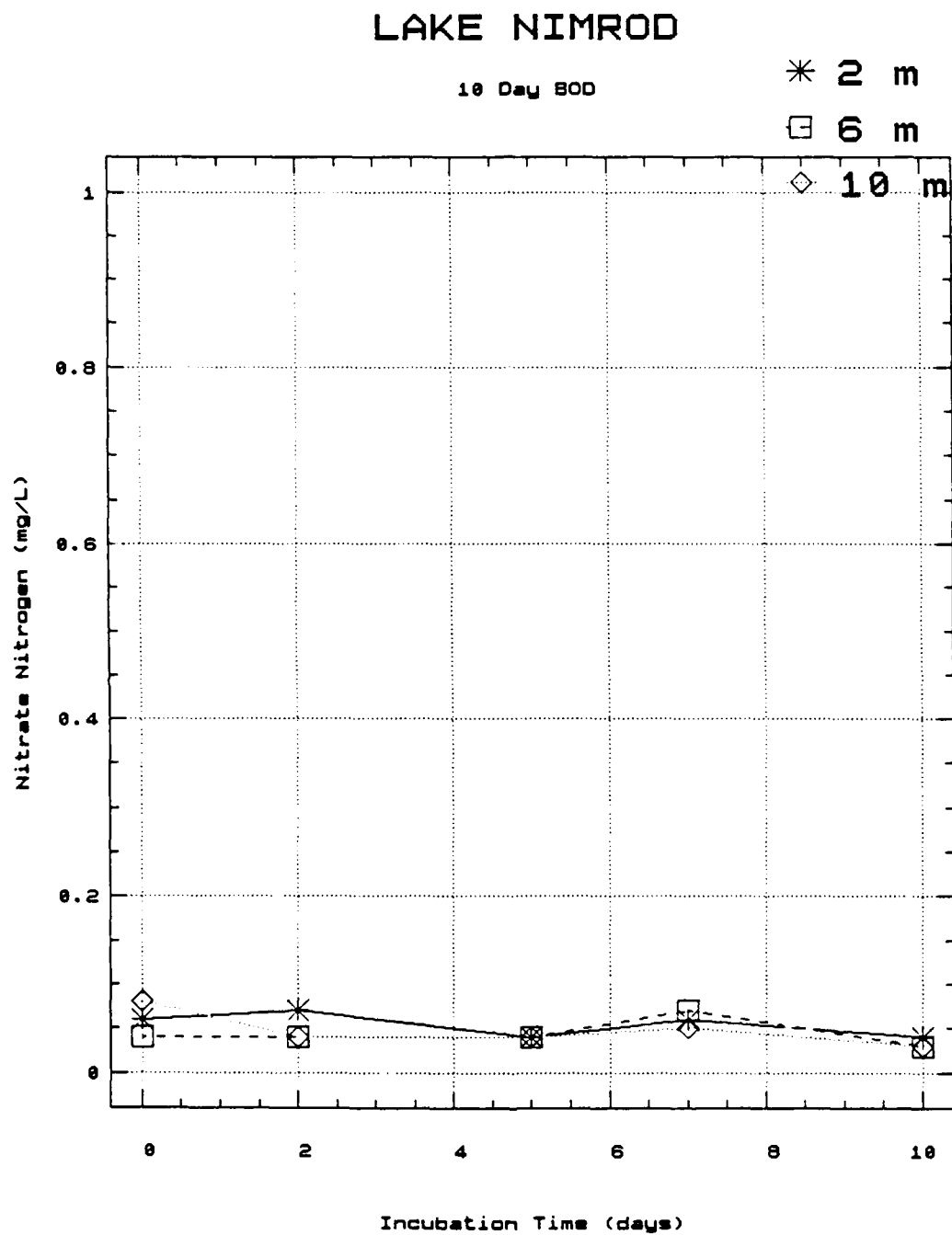
Figure 84. Lake Nimrod, July 6, 1988,
10-day BOD, mean nitrate nitrogen

C84

LAKE NIMROD

10 Day BOD

✳ 2 m

⊟ 6 m

◇ 10 m
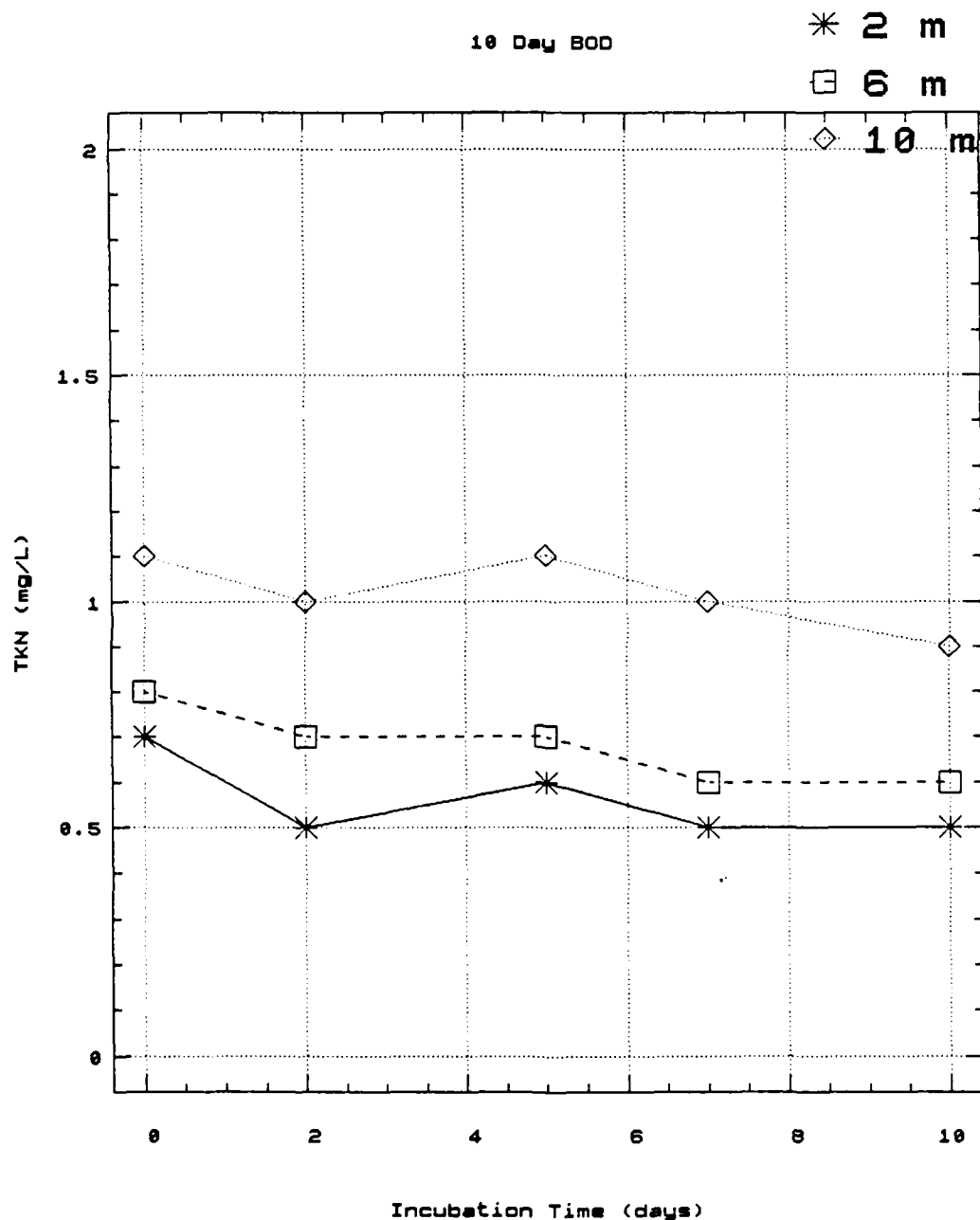
Figure C85. Lake Nimrod, July 6, 1988, 10-day
BOD, mean total Kjeldahl nitrogen
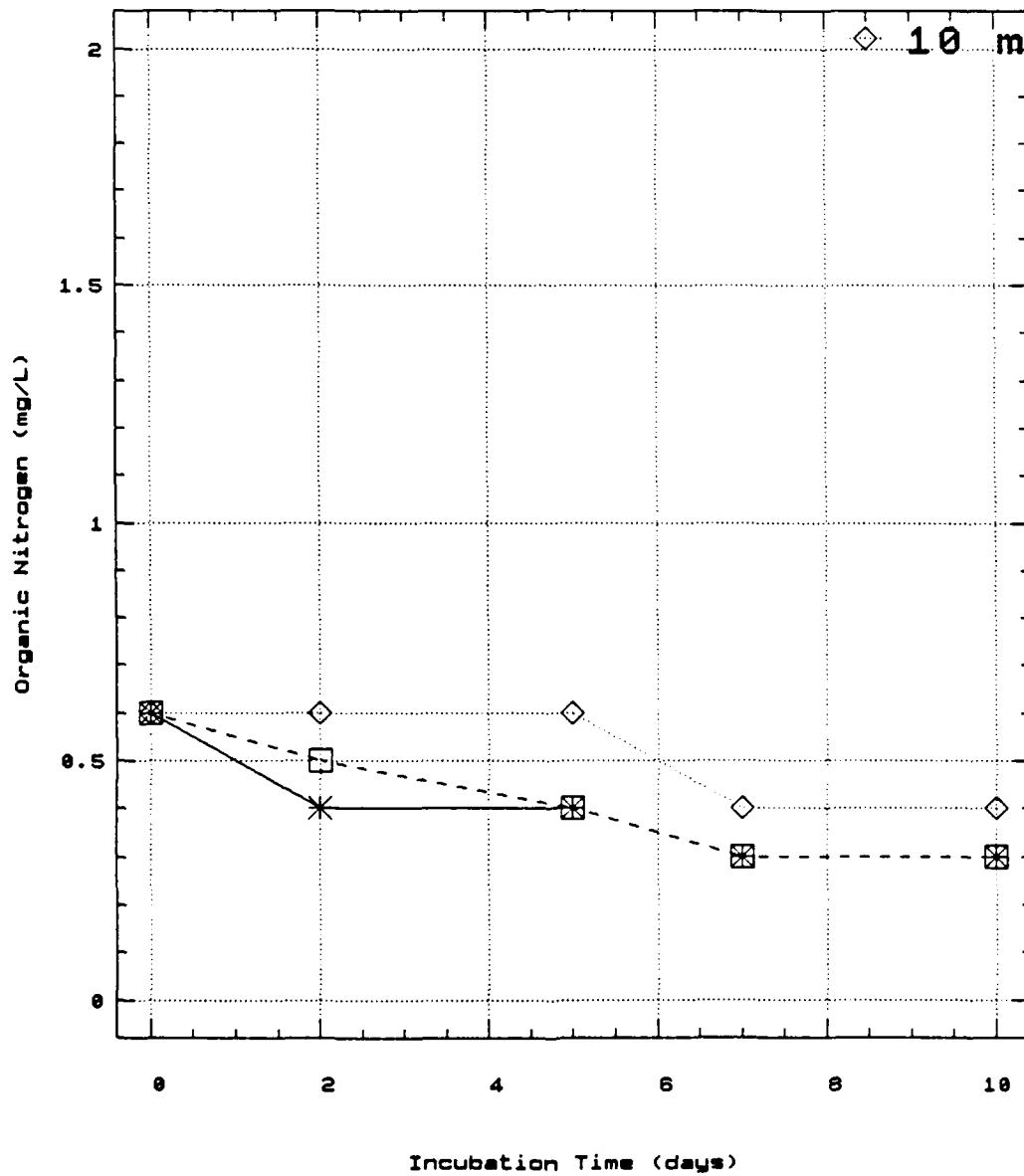
Figure C86. Lake Nimrod, July 6, 1988,
10-day BOD, mean organic nitrogen

LAKE NIMROD
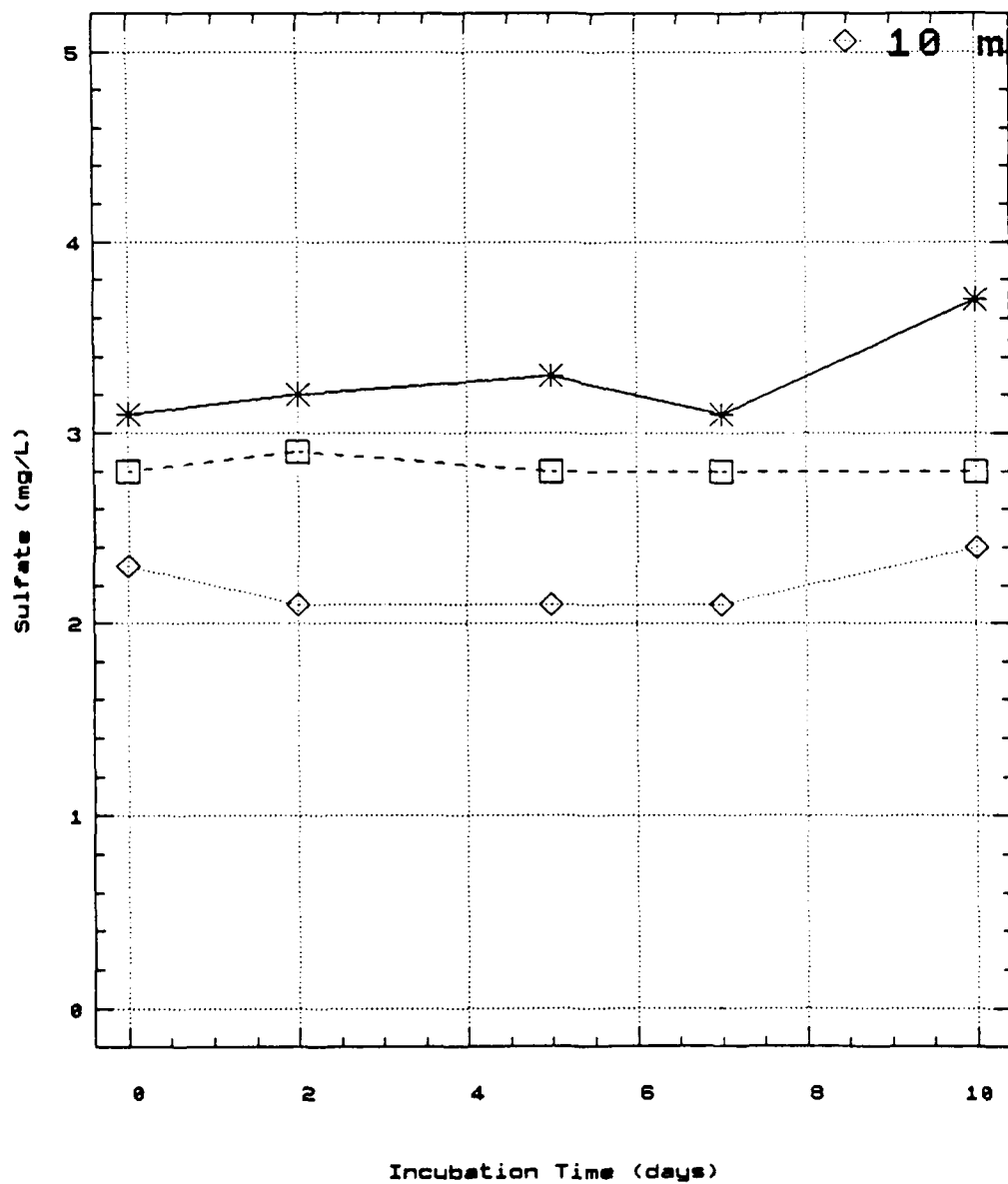
10 Day BOD

Figure C87. Lake Nimrod, July 6, 1988,
10-day BOD, mean sulfate
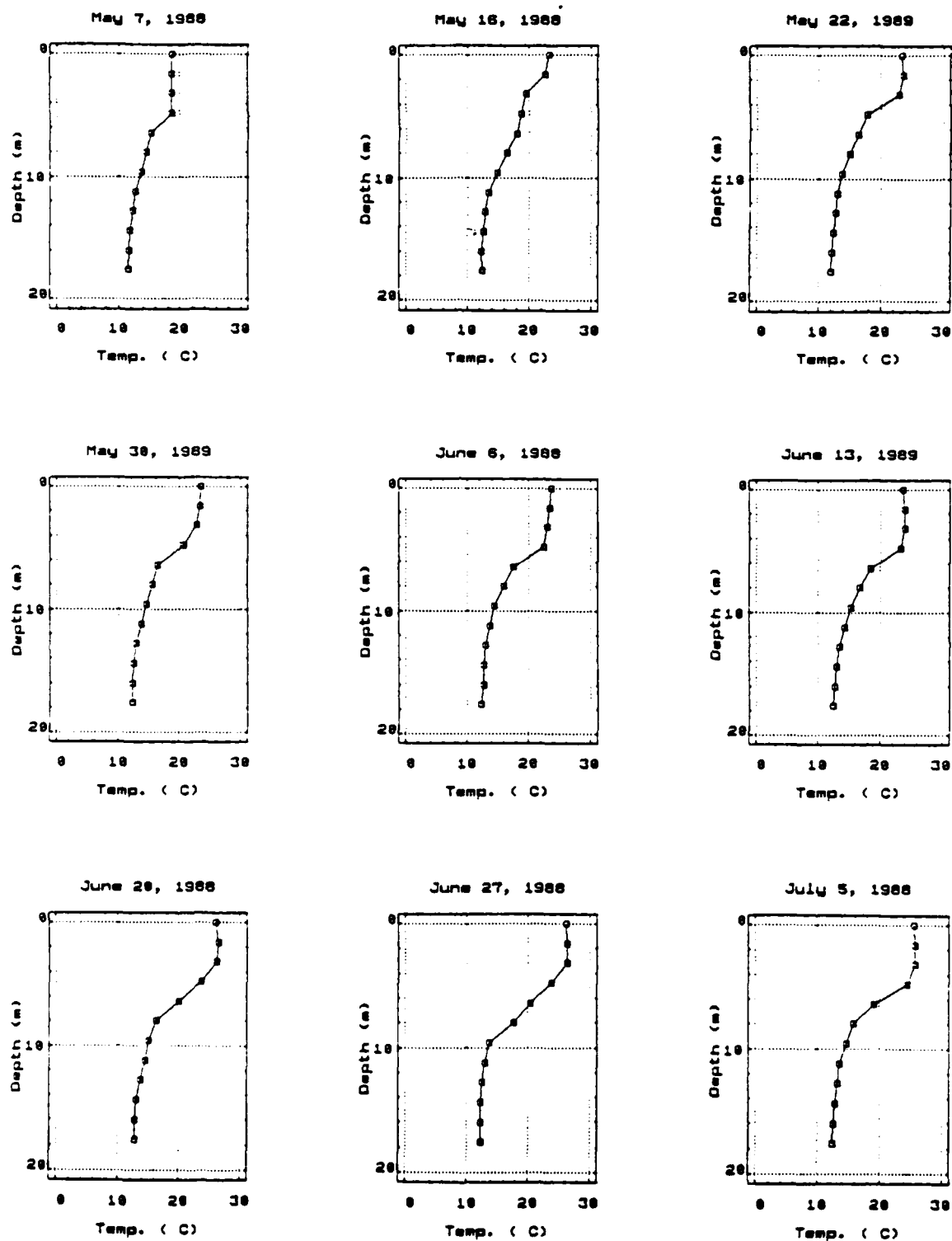
Figure C88. Rough River Lake, temperature profiles
(Continued)

C88
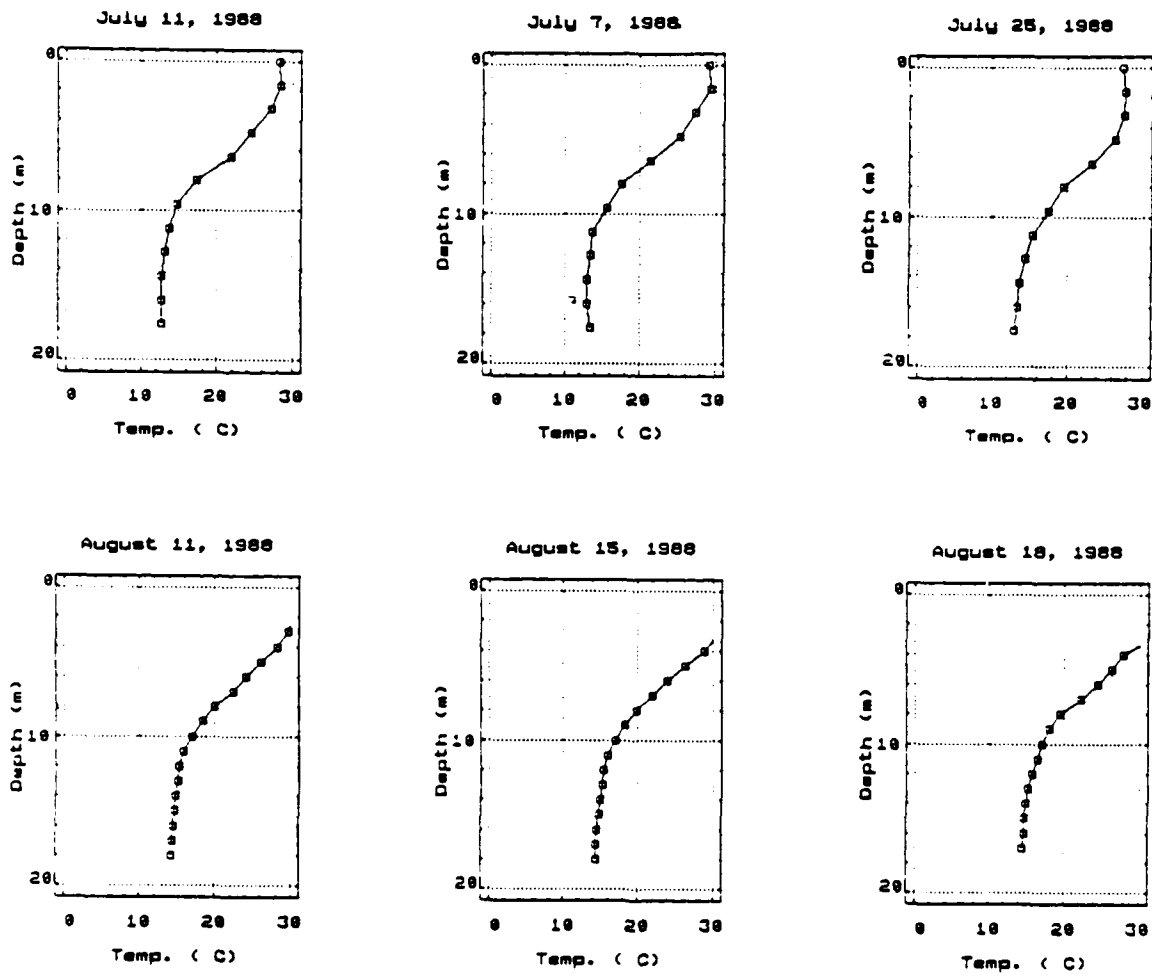
Figure C88. (Concluded)
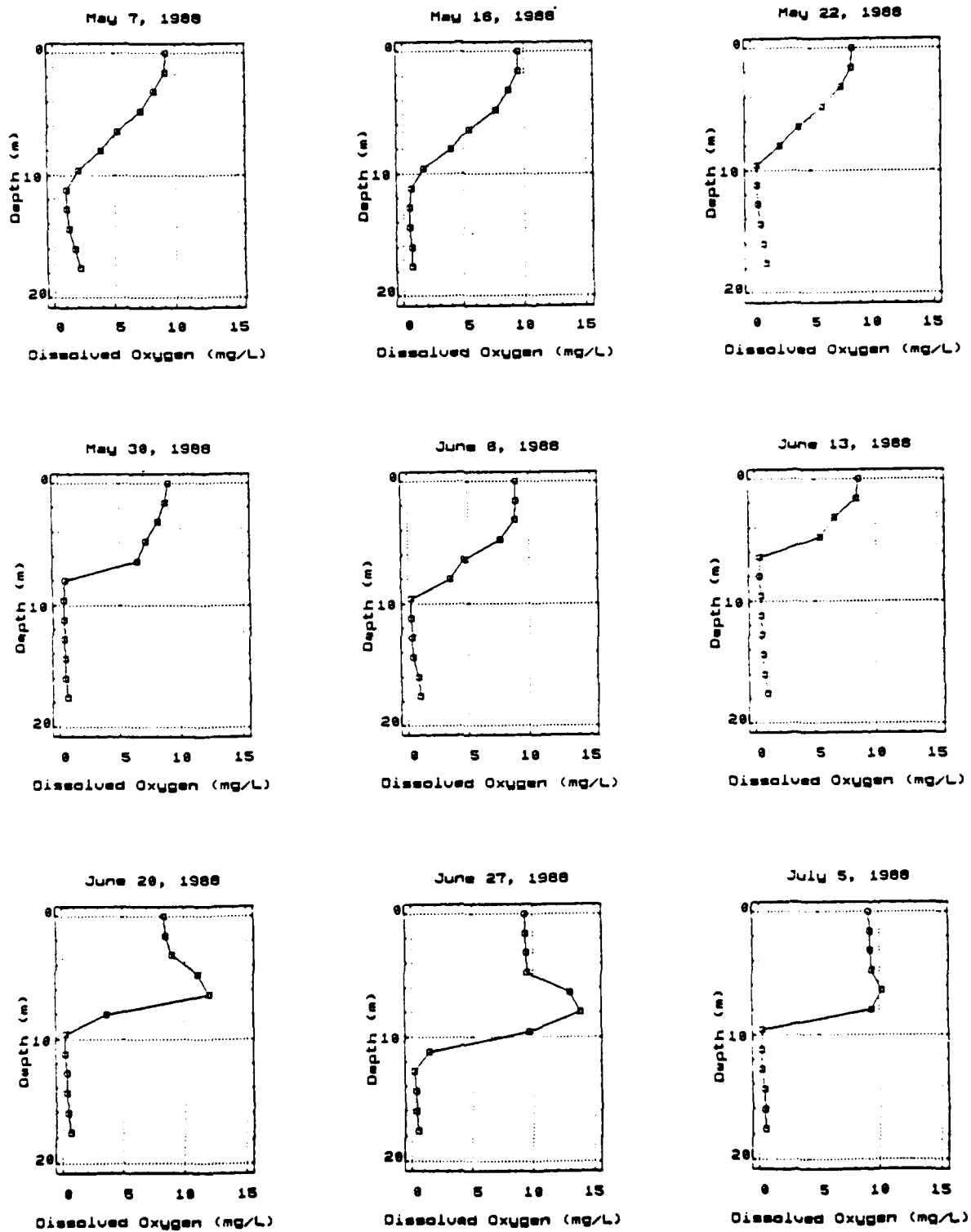
Figure C89. Rough River Lake, DO profiles (Continued)
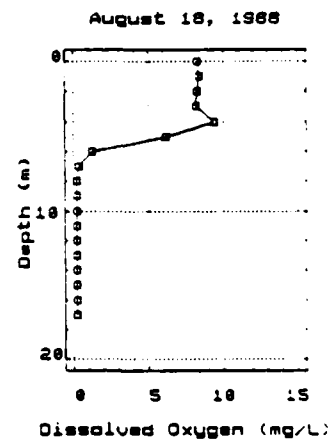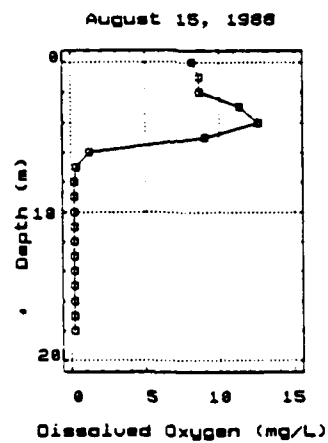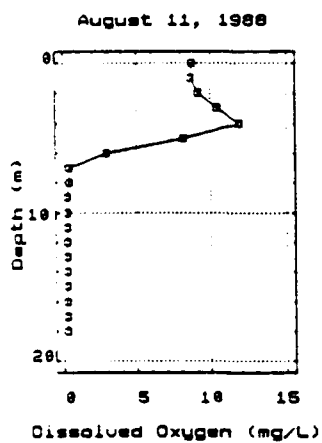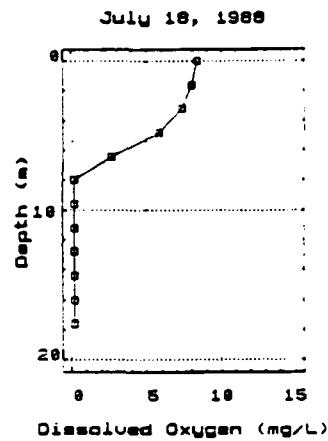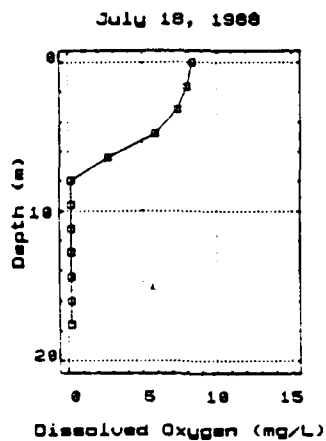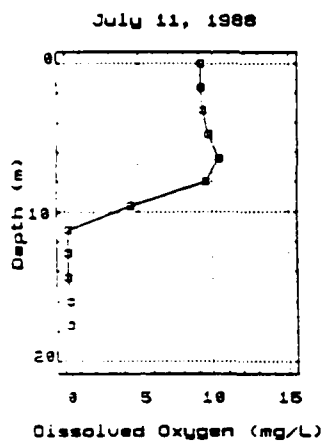
Figure C89.   (Concluded)

C91

ROUGH RIVER TAILWATER
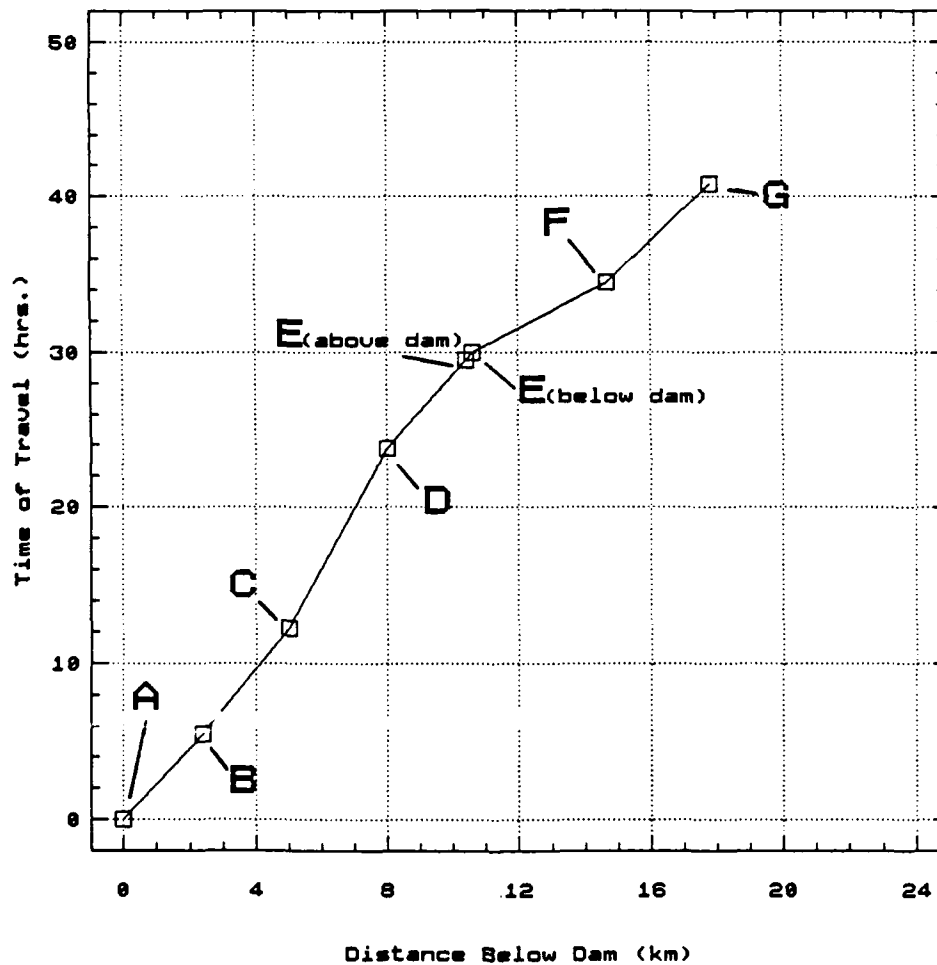
August 1988

Figure C90. Rough River tailwater, time of
travel versus distance below dam

ROUGH RIVER TAILWATER
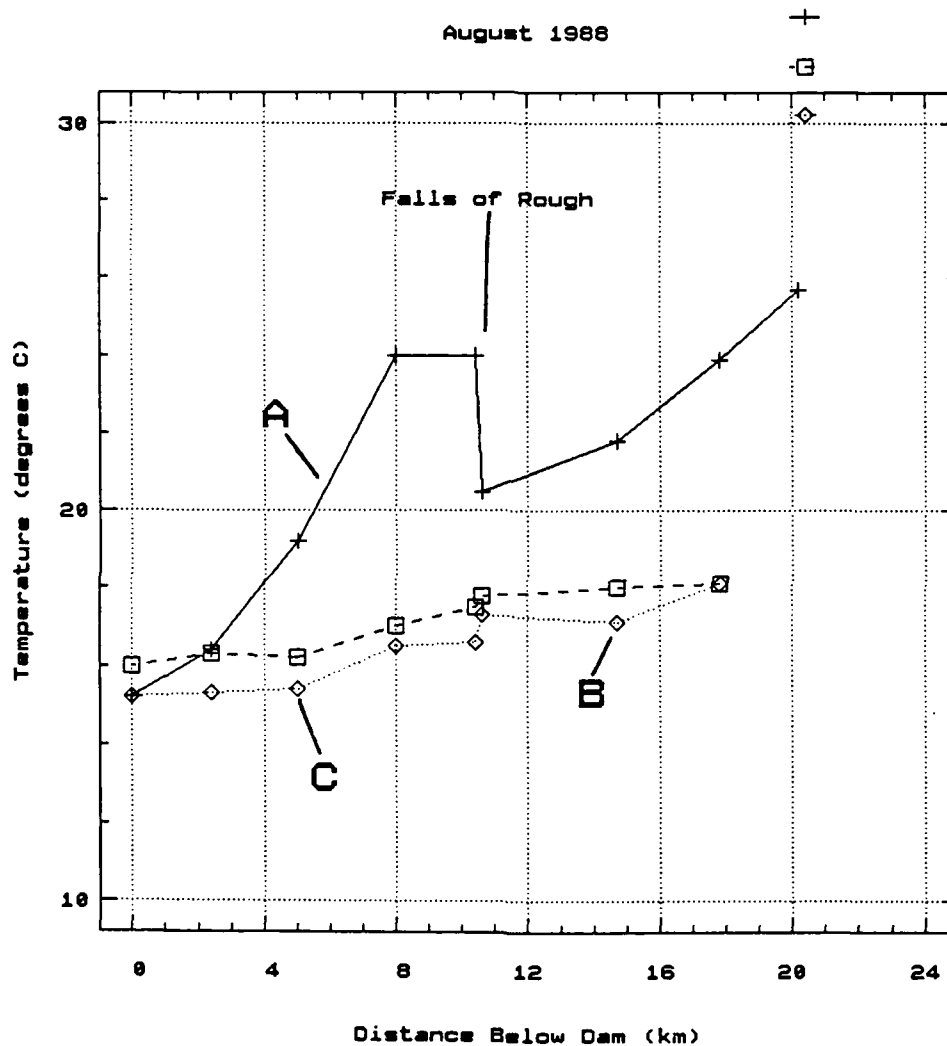
August 1988

Figure C91. Rough River tailwater, tempera-
ture versus distance below dam on 8/16/88-
8/18/88 (A = low flow, steady state; B =
high flow, time of travel; C = high flow,
steady state)

ROUGH RIVER TAILWATER
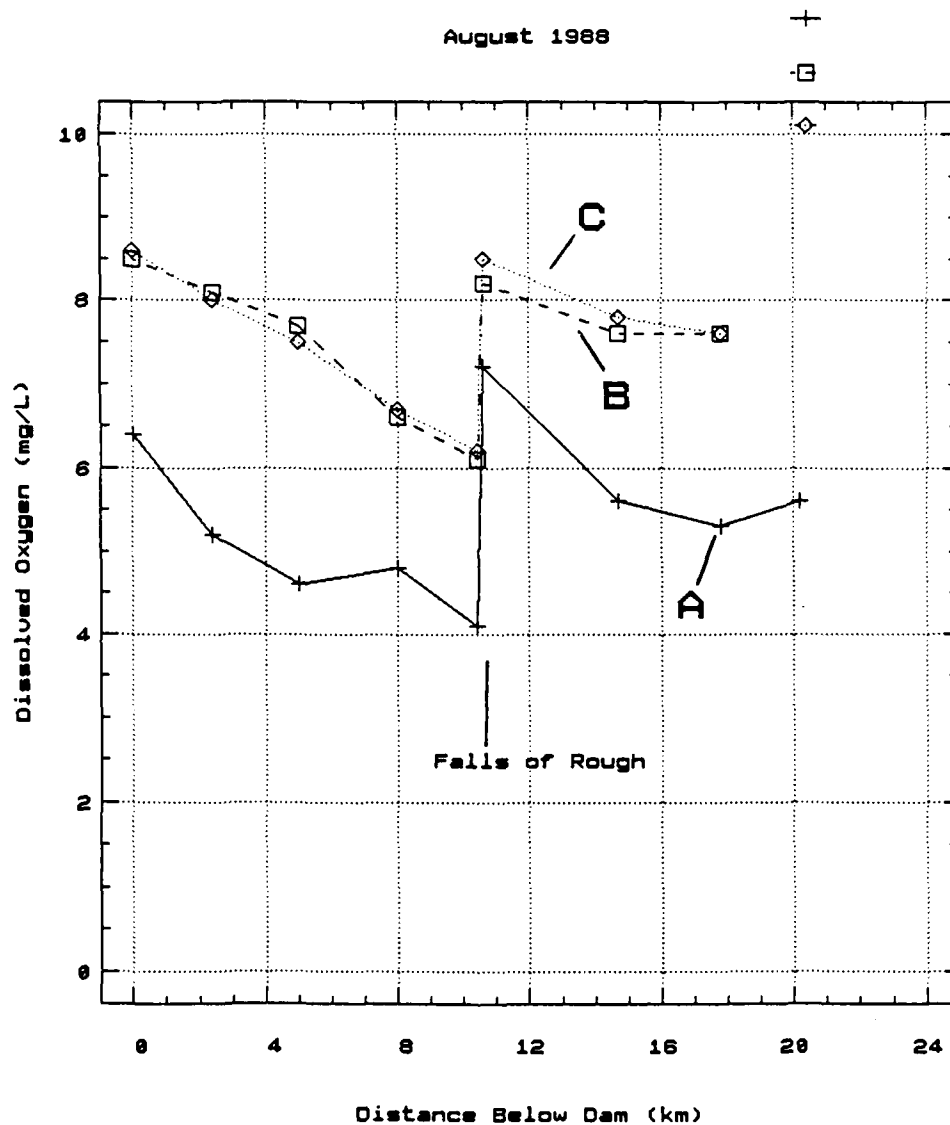
August 1988

Figure C92. Rough River tailwater, DO versus
distance below dam on 8/16/88-8/18/88 (A =
low flow, steady state; B = high flow, time
of travel; C = high flow, steady state)

ROUGH RIVER TAILWATER
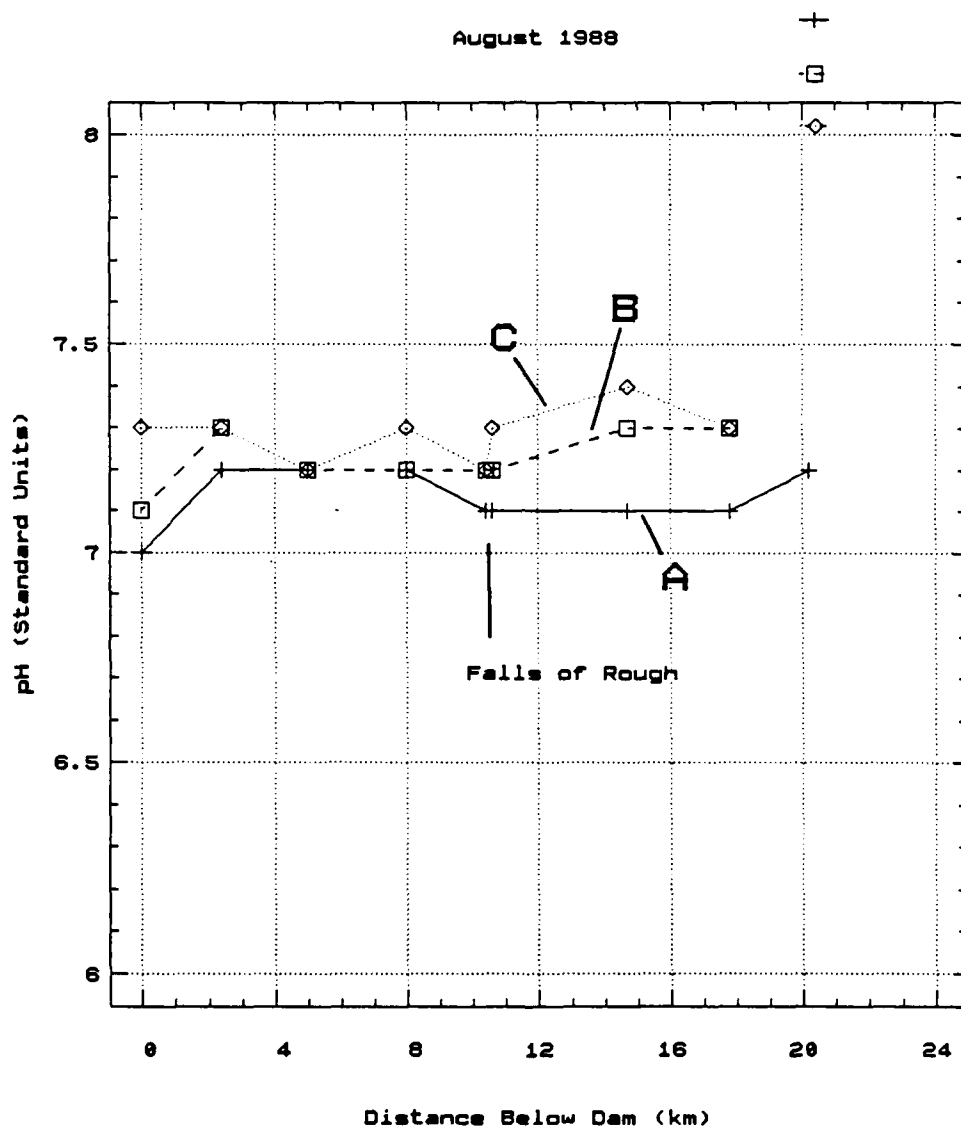
August 1988

Figure C93. Rough River tailwater, pH versus
distance below dam on 8/16/88-8/18/88 (A =
low flow, steady state; B = high flow, time of
travel; C = high flow, steady state)
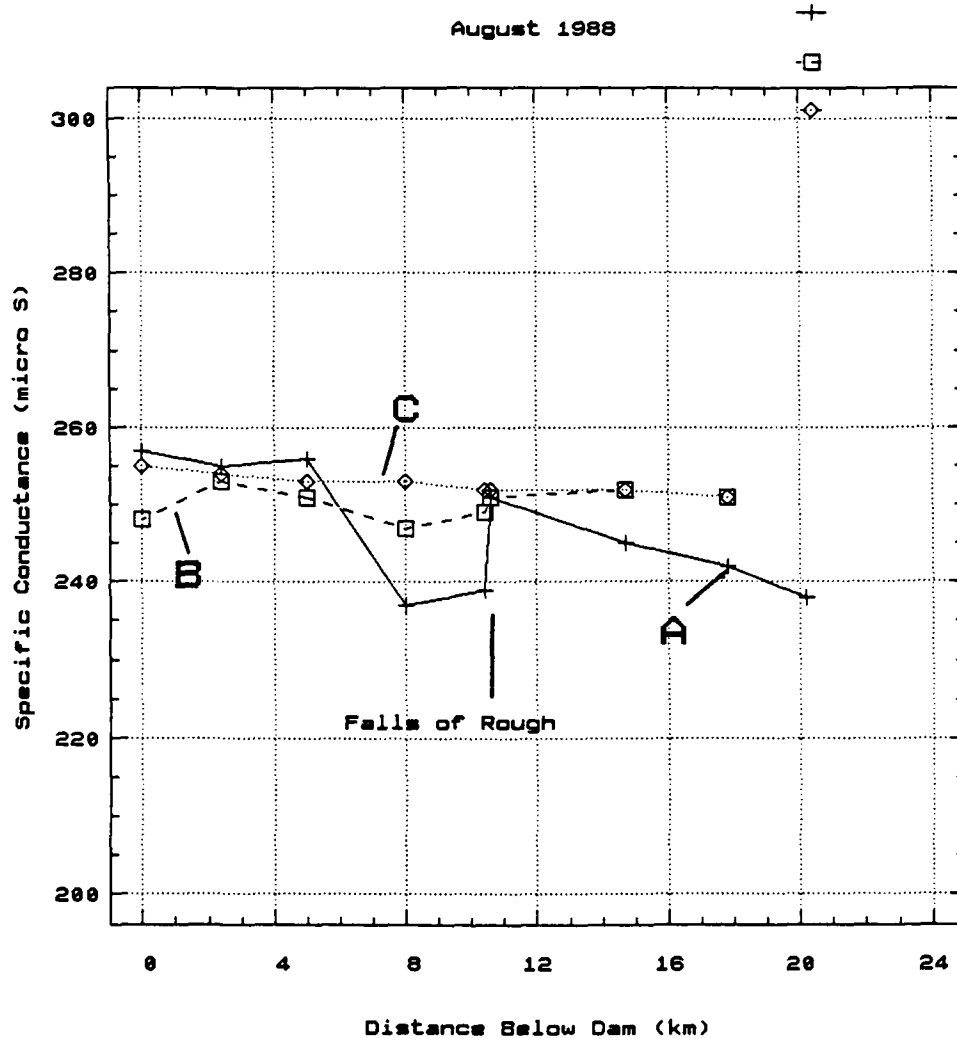
Figure C94. Rough River tailwater, specific
conductance versus distance below dam on
8/16/88-8/18/88 (A = low flow, steady state;
B = high flow, time of travel; C = high
flow, steady state)
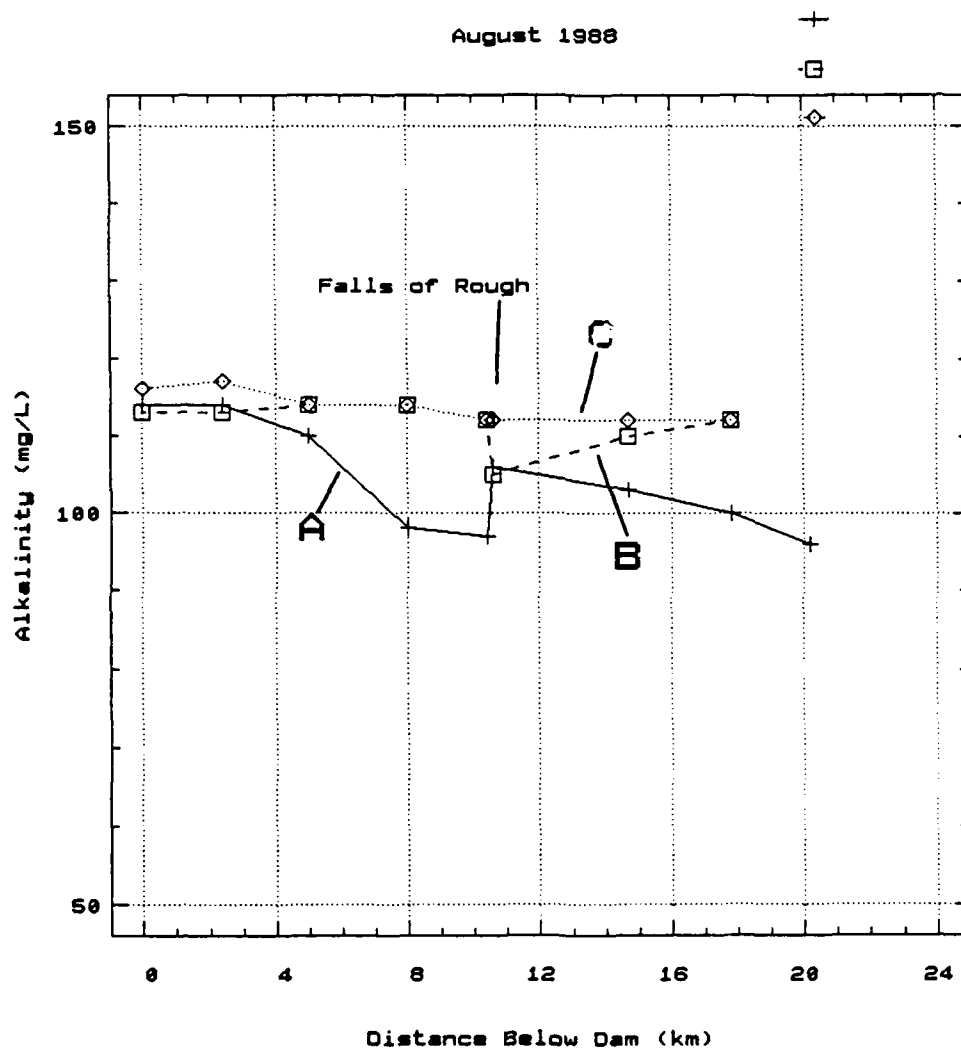
Figure C95. Rough River tailwater, alkalinity
versus distance below dam on 8/16/88-8/18/88
(A = low flow, steady state; B = high flow,
time of travel; C = high flow, steady state)

Figure C96. Rough River tailwater, total
organic carbon versus distance below dam
on 8/16/88-8/18/88 (A = low flow, steady
state; B = high flow, time of travel; C =
high flow, steady state)

C98

ROUGH RIVER TAILWATER
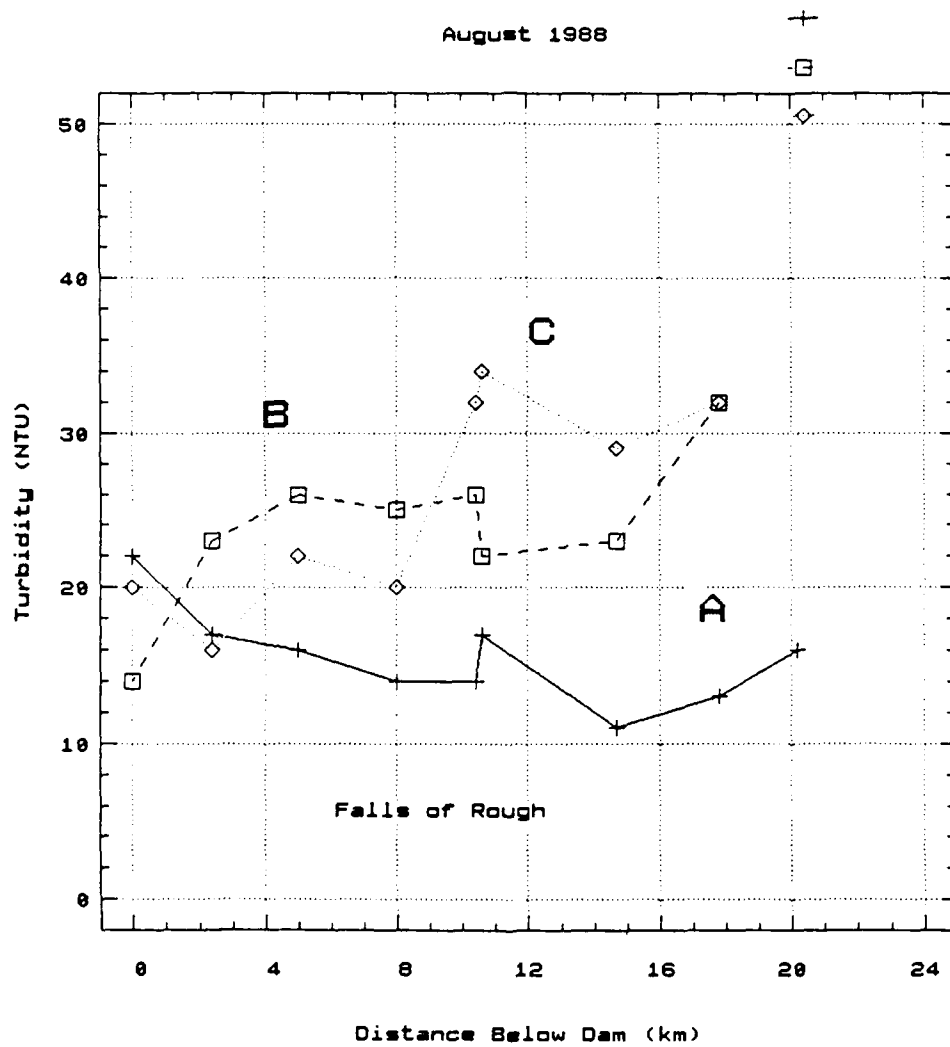
August 1988

Figure C97. Rough River tailwater, turbidity versus distance below dam on 8/16/88-8/18/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)

ROUGH RIVER TAILWATER
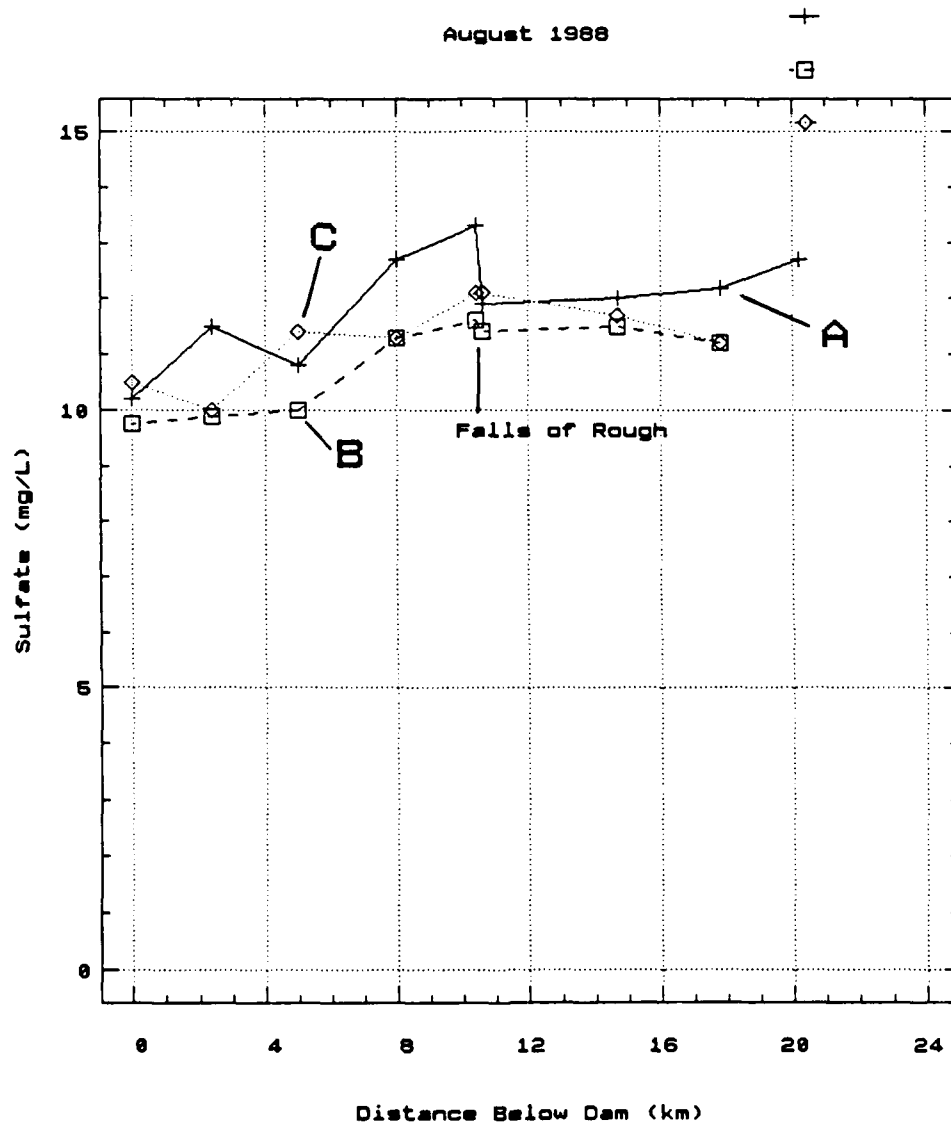
August 1988

Figure C98. Rough River tailwater, sulfate versus distance below dam on 8/16/88-8/18/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)

C100

ROUGH RIVER TAILWATER

August 1988

Figure C99. Rough River tailwater, total manganese versus distance below dam on 8/16/88-8/18/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)

Figure C100. Rough River tailwater, dis-
solved manganese versus distance below
dam on 8/16/88-8/18/88 (A = low flow,
steady state; B = high flow, time of
    travel; C = high flow, steady state)

Figure C101. Rough River tailwater, total iron versus distance below dam on 8/16/88-8/18/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)

ROUGH RIVER TAILWATER

August 1988

Figure C102. Rough River tailwater, dissolved iron versus distance below dam on 8/16/88-8/18/88 (A — low flow, steady state; B — high flow, time of travel; C = high flow, steady state)

ROUGH RIVER TAILWATER

August 1988

Figure C103. Rough River tailwater, nitrate
nitrogen versus distance below dam on
8/16/88-8/18/88 (A = low flow, steady state;
B = high flow, time of travel; C = high
flow, steady state)
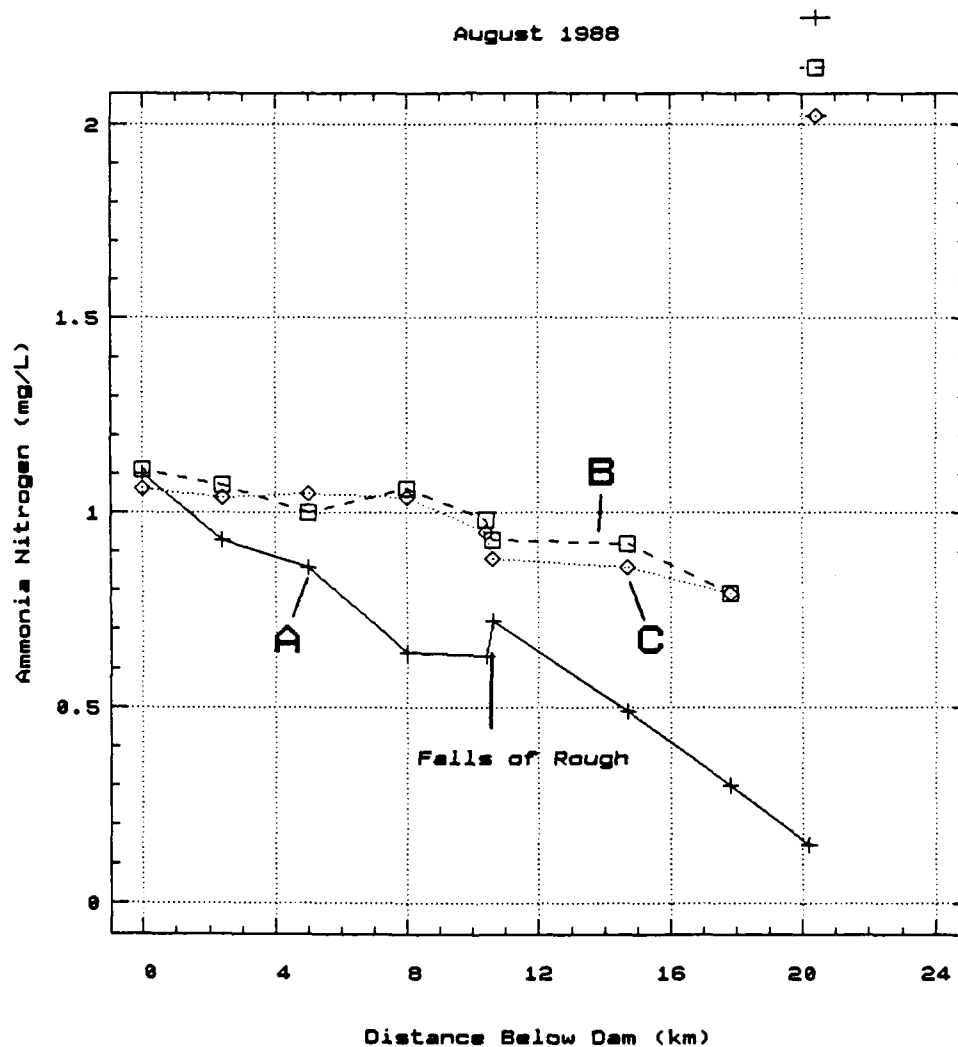
Figure C104. Rough River tailwater, ammonia nitrogen versus distance below dam on 8/16/88-8/18/88 (A = low flow, steady state; B = high flow, time of travel; C = high flow, steady state)
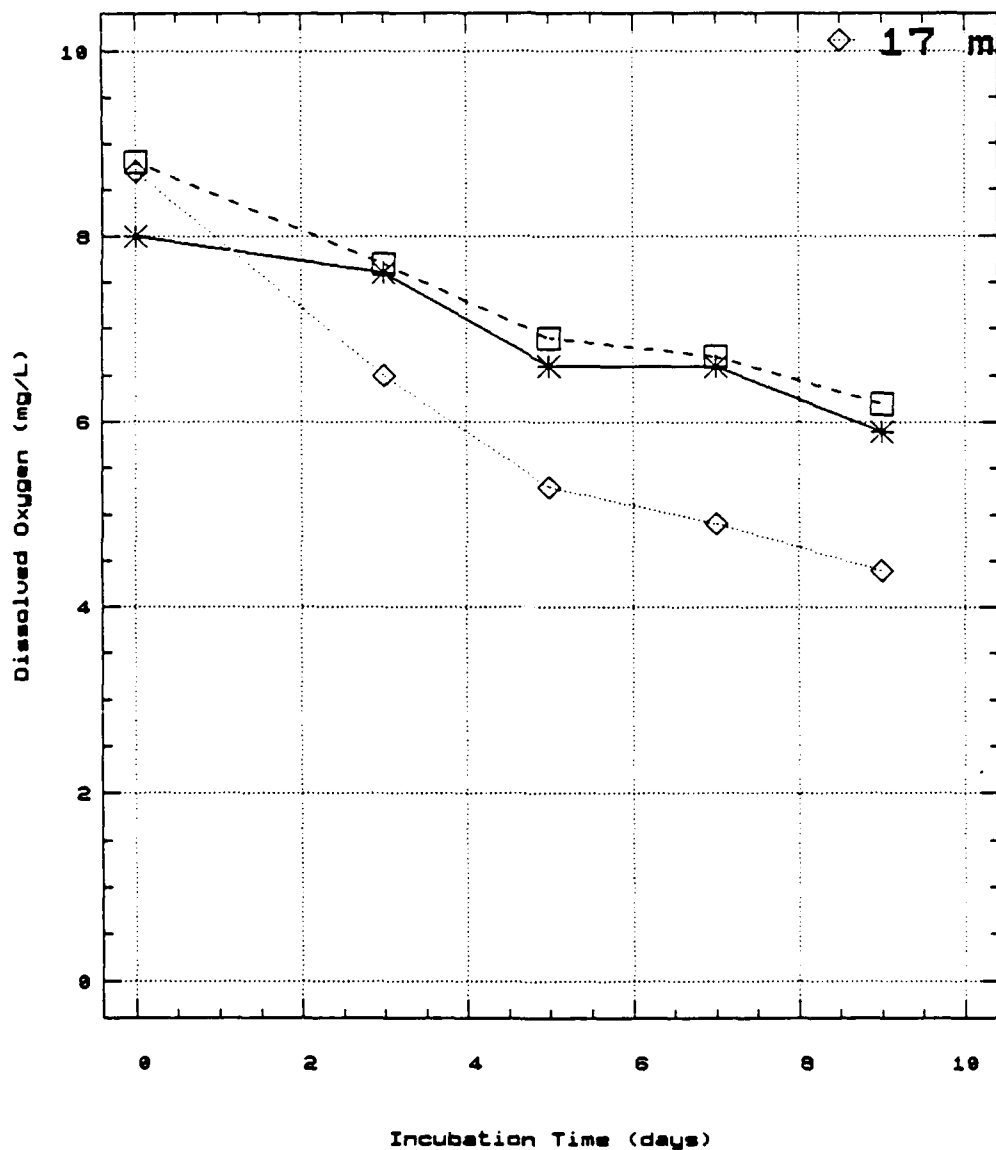
Figure C105. Rough River Lake, August 11, 1988, 10-day BOD, mean DO
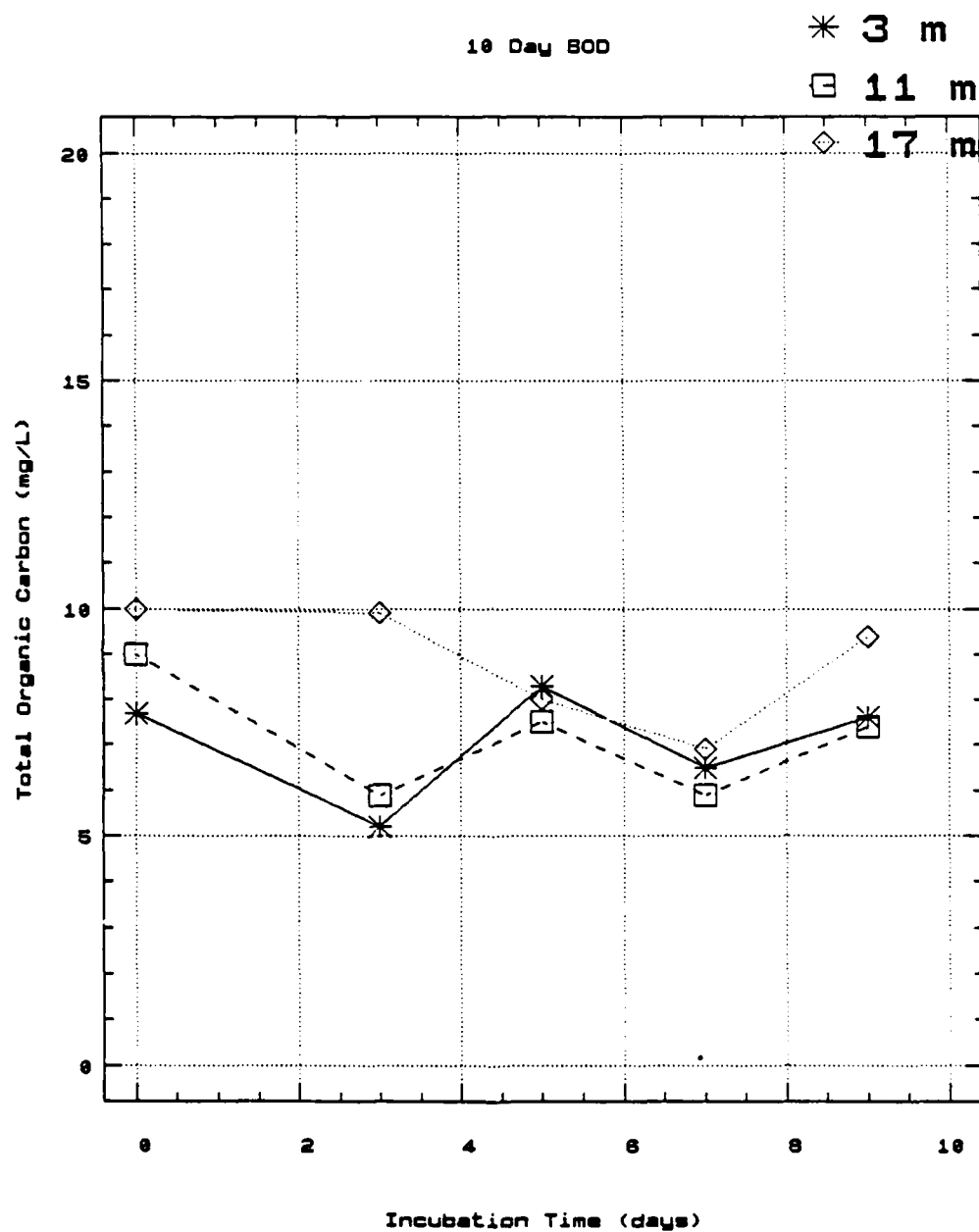
Figure C106. Rough River Lake, August 11, 1988,
10-day BOD, mean total organic carbon
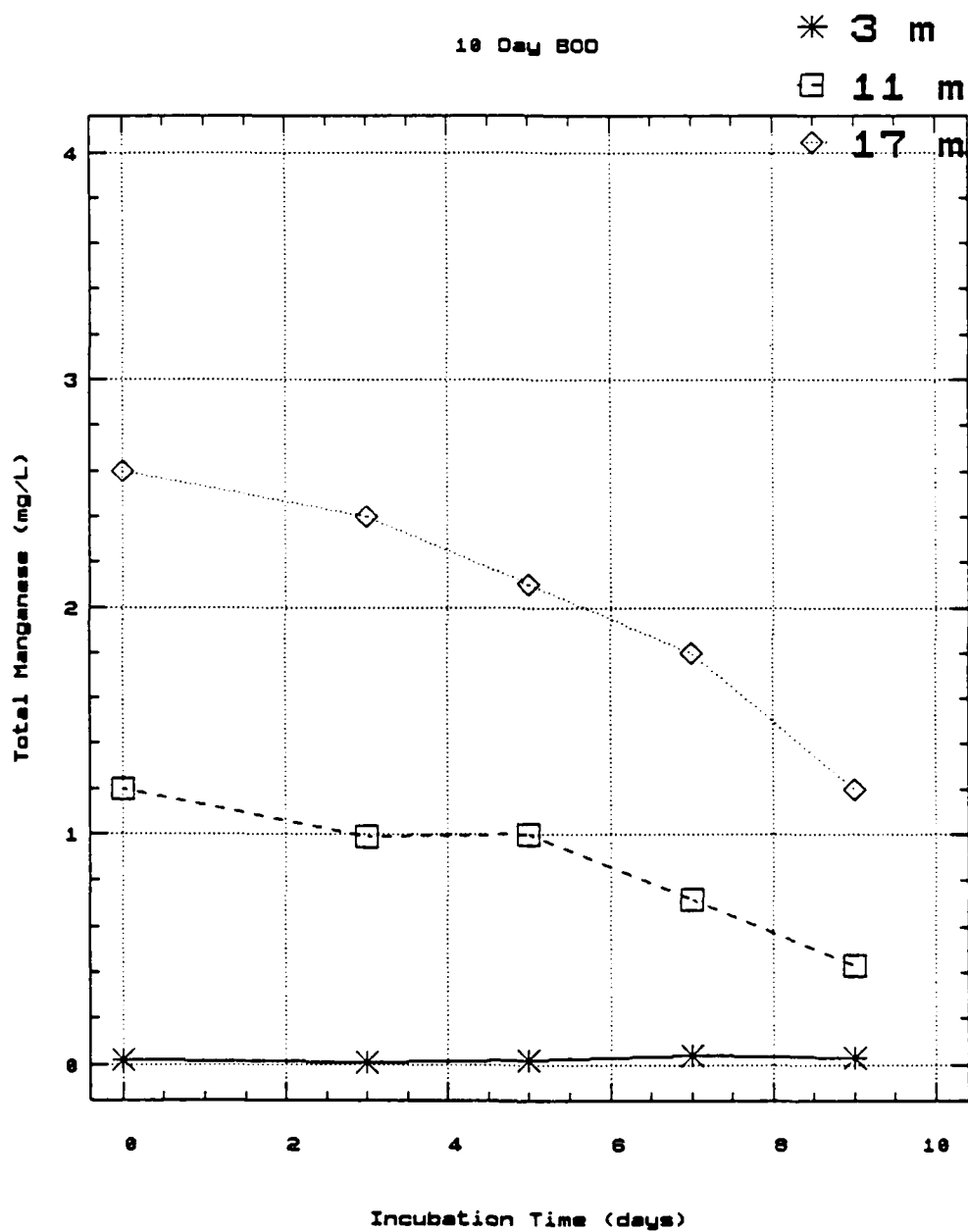
Figure C107. Rough River Lake, August 11, 1988,
10-day BOD, mean total manganese

ROUGH RIVER LAKE

10 Day BOD

✳ **3 m**

⊟ **11 m**

◇ **17 m**
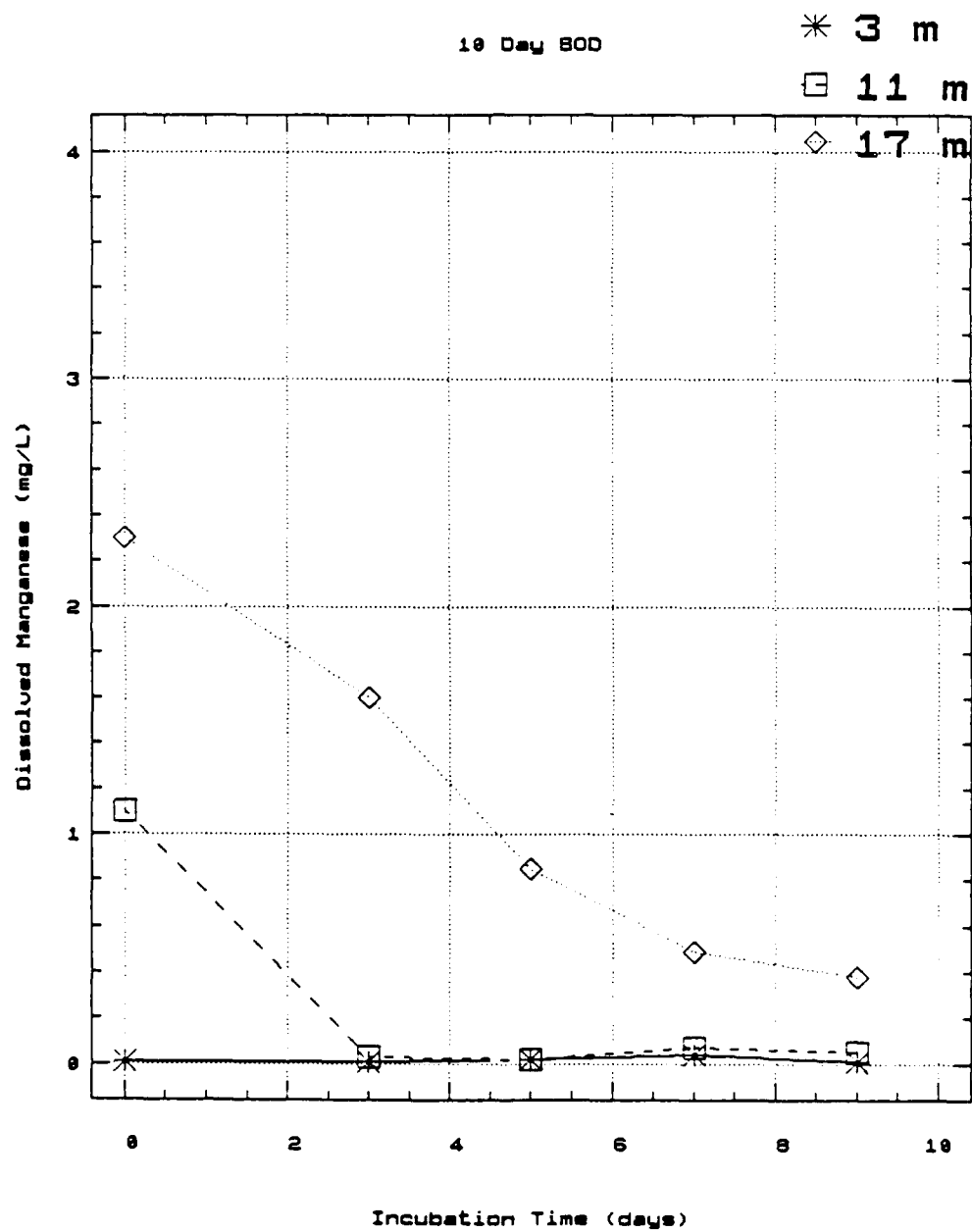
Figure C108. Rough River Lake, August 11, 1988,
10-day BOD, mean dissolved manganese
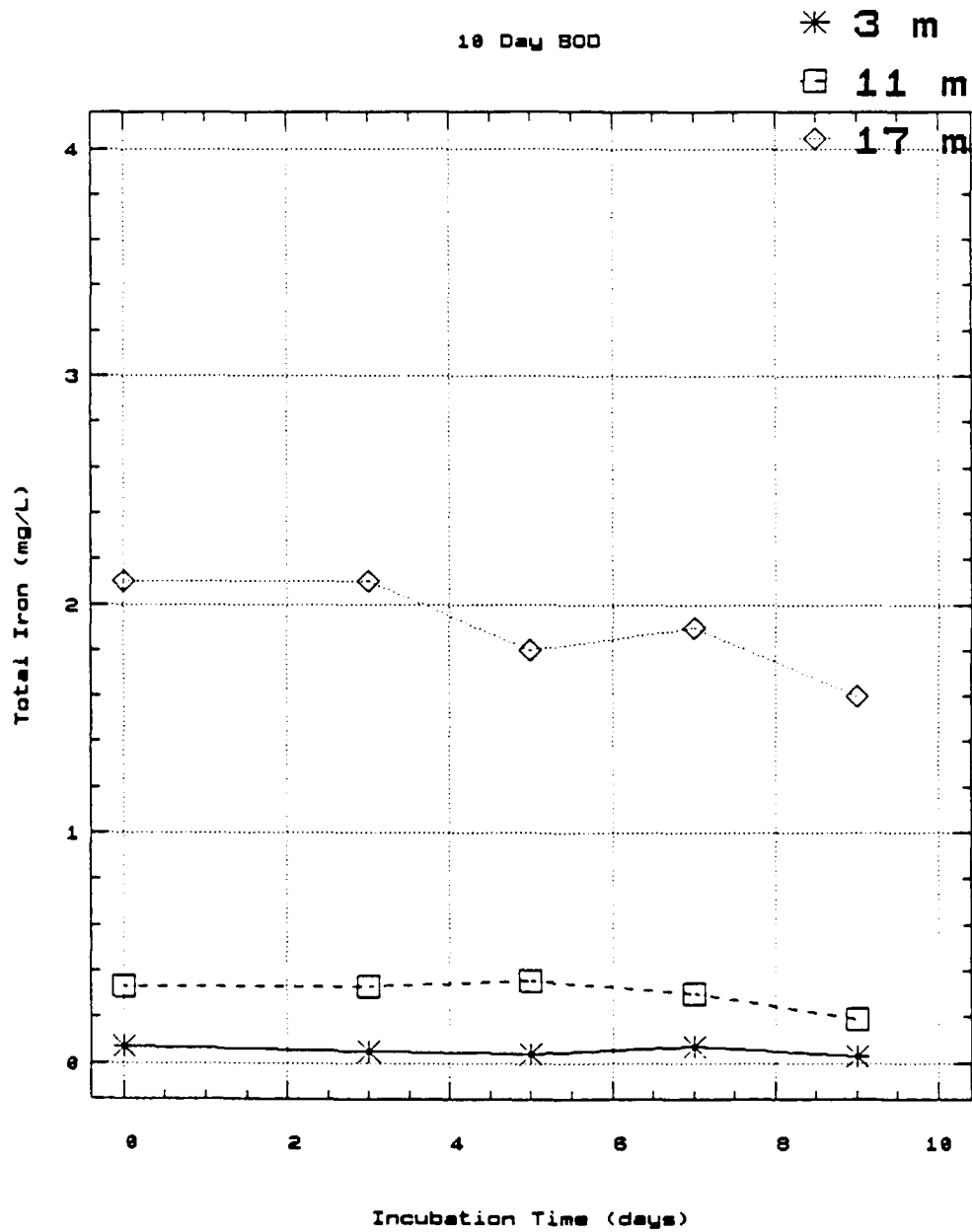
Figure C109.   Rough River Lake, August 11, 1988,
10-day BOD, mean total iron

ROUGH RIVER LAKE

10 Day BOD

✳ **3 m**

⊟ **11 m**

◇ **17 m**
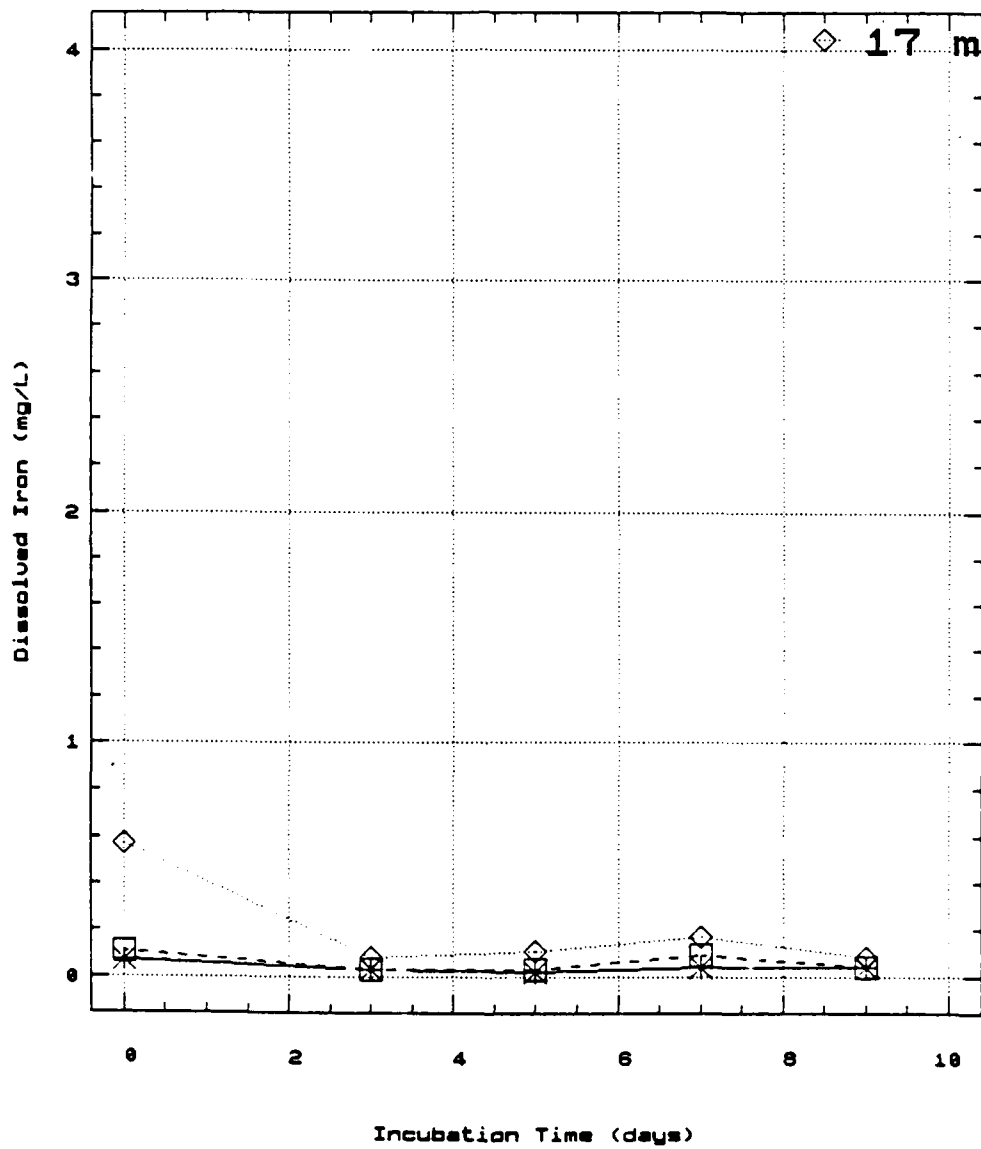
Figure C110. Rough River Lake, August 11, 1988,
10-day BOD, mean dissolved iron

C112

ROUGH RIVER LAKE
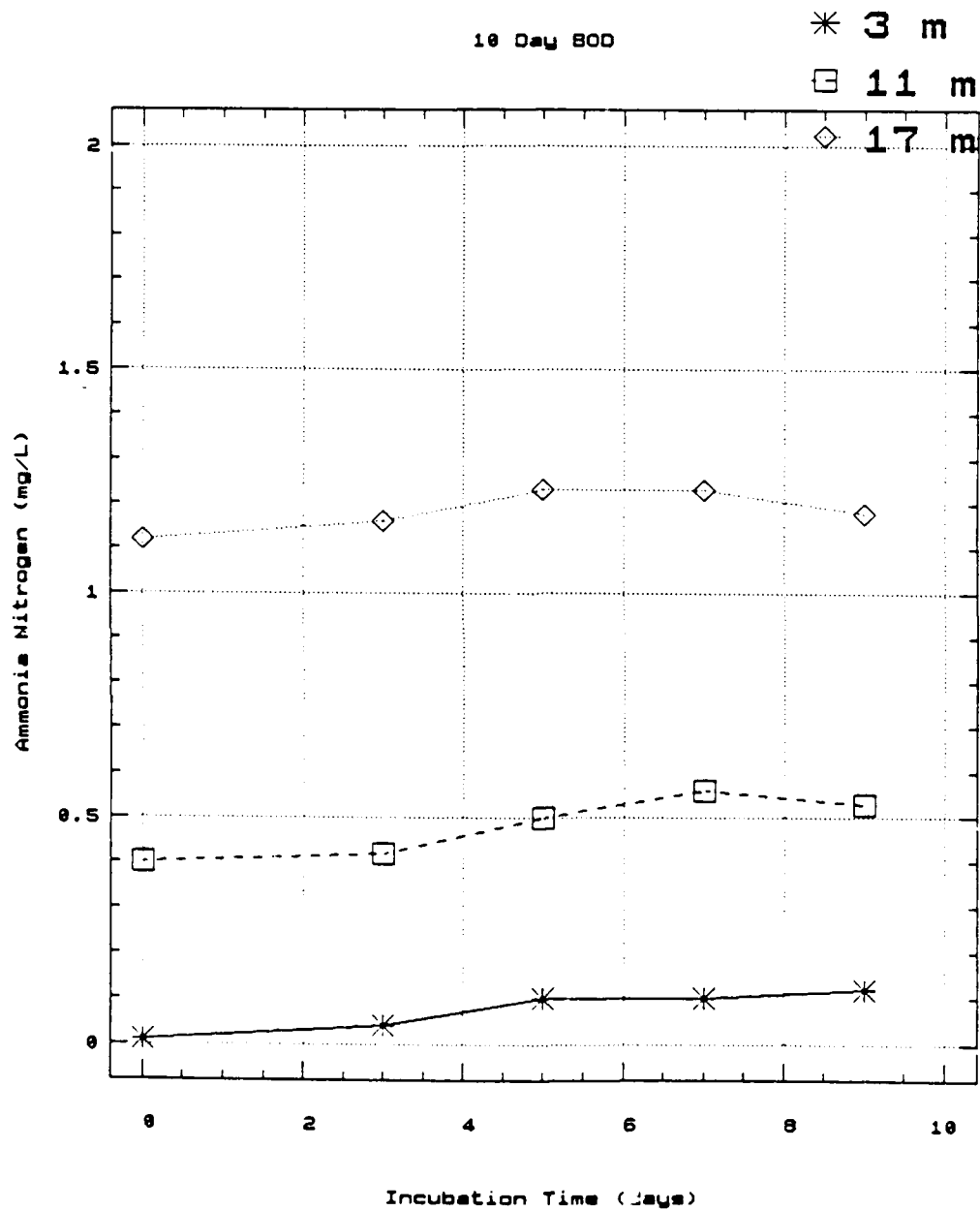
10 Day BOD

Figure C111. Rough River Lake, August 11, 1988, 10-day BOD, mean ammonia nitrogen

C112

ROUGH RIVER LAKE
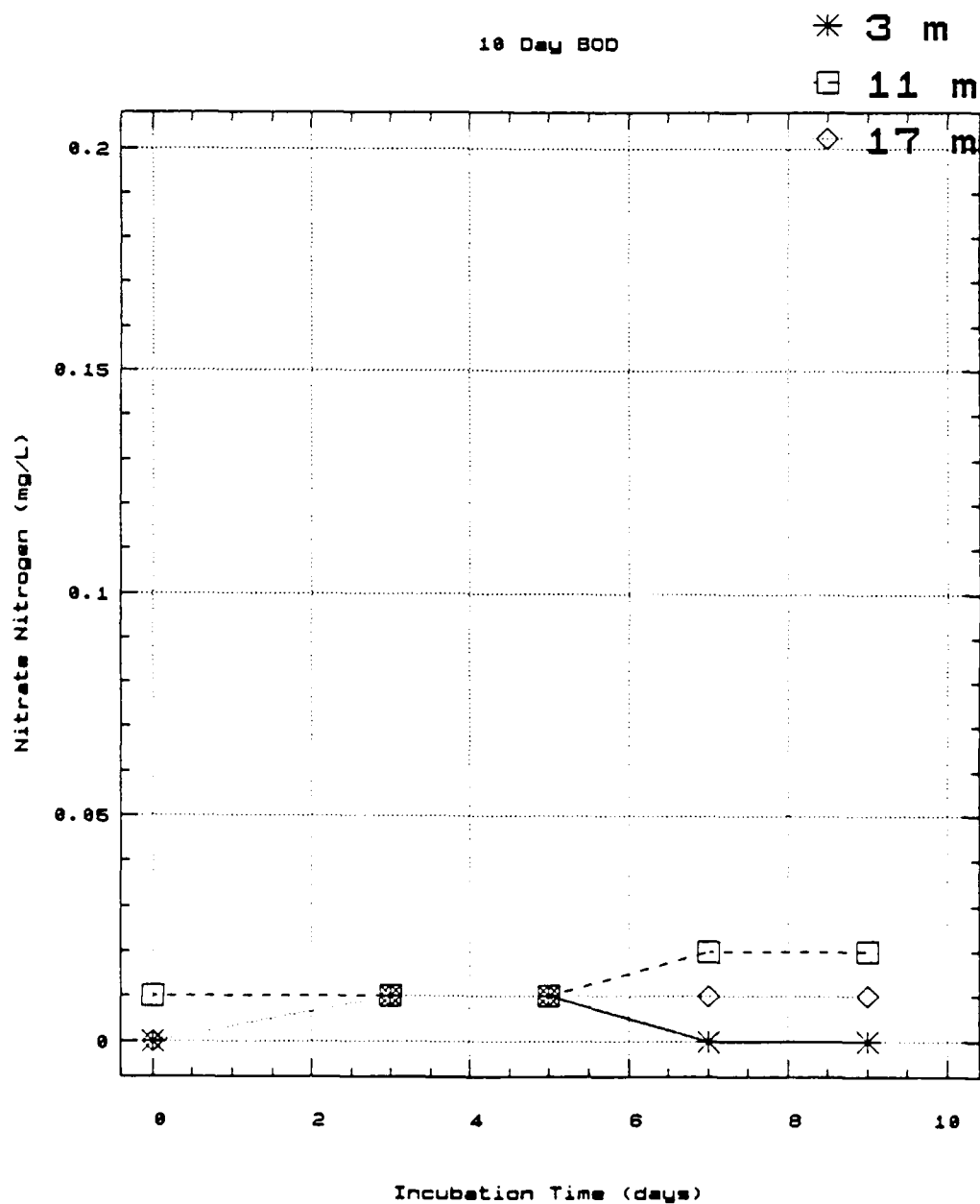
10 Day BOD

Figure C112.   Rough River Lake, August 11, 1988,
10-day BOD, mean nitrate nitrogen

ROUGH RIVER LAKE

10 Day BOD

✳ **3 m**

⊟ **11 m**

◇ **17 m**
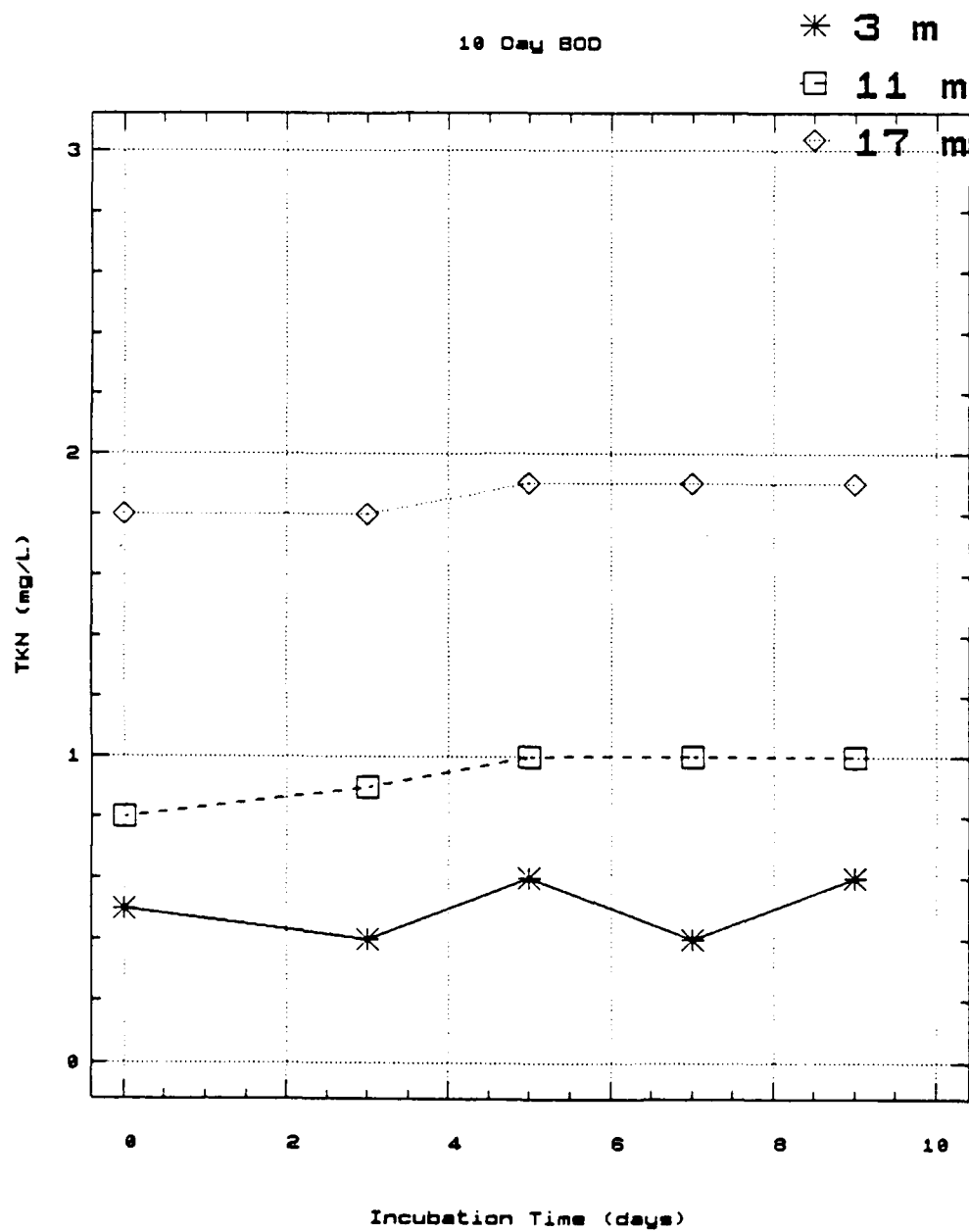
Figure C113. Rough River Lake, August 11, 1988, 10-day BOD, mean total Kjeldahl nitrogen
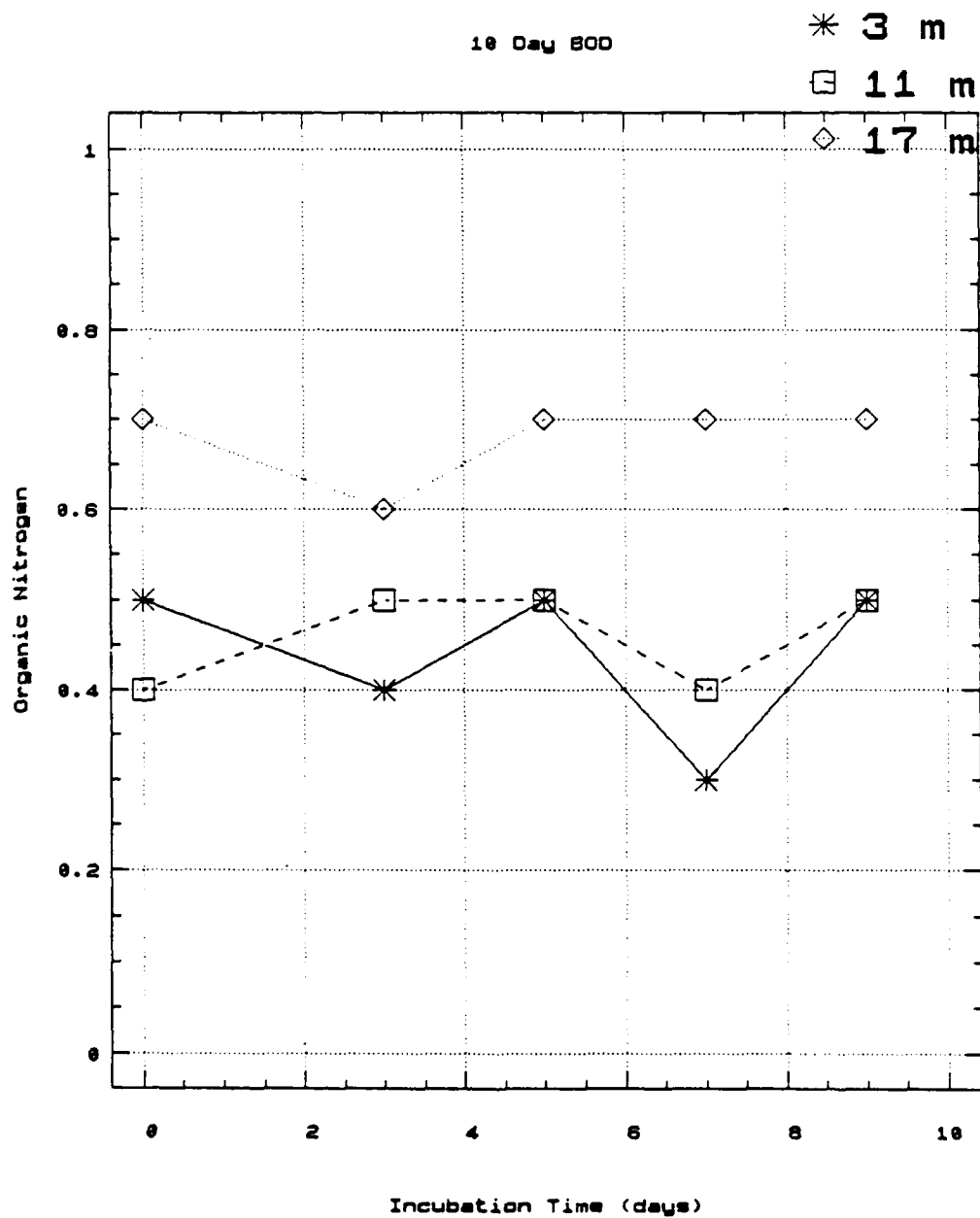
Figure C114. Rough River Lake, August 11, 1988,
10-day BOD, mean organic nitrogen

ROUGH RIVER LAKE

10 Day BOD

✳ **3 m**

⊟ **11 m**

◇ **17 m**
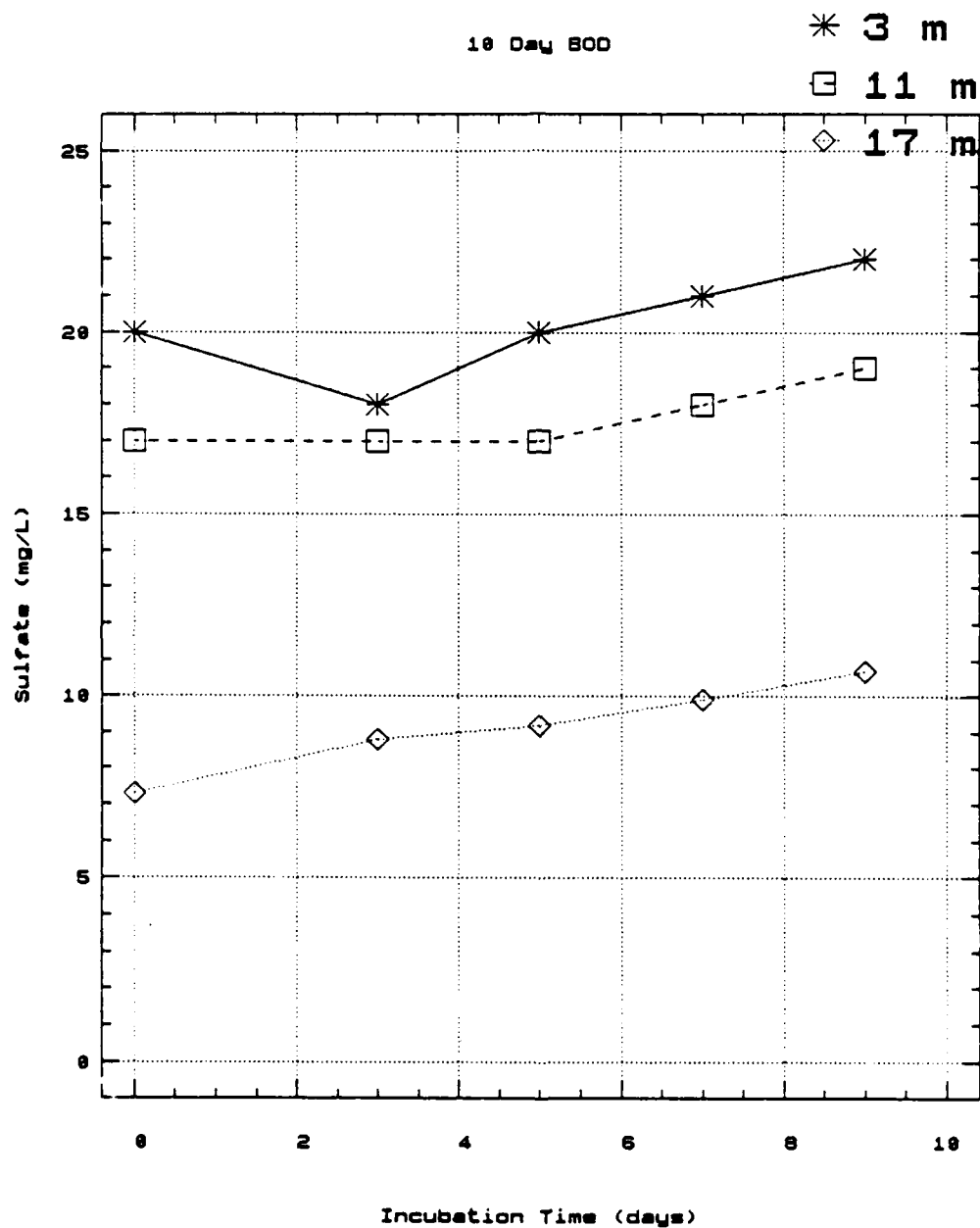
Figure C115. Rough River Lake, August 11, 1988,
10-day BOD, mean sulfate
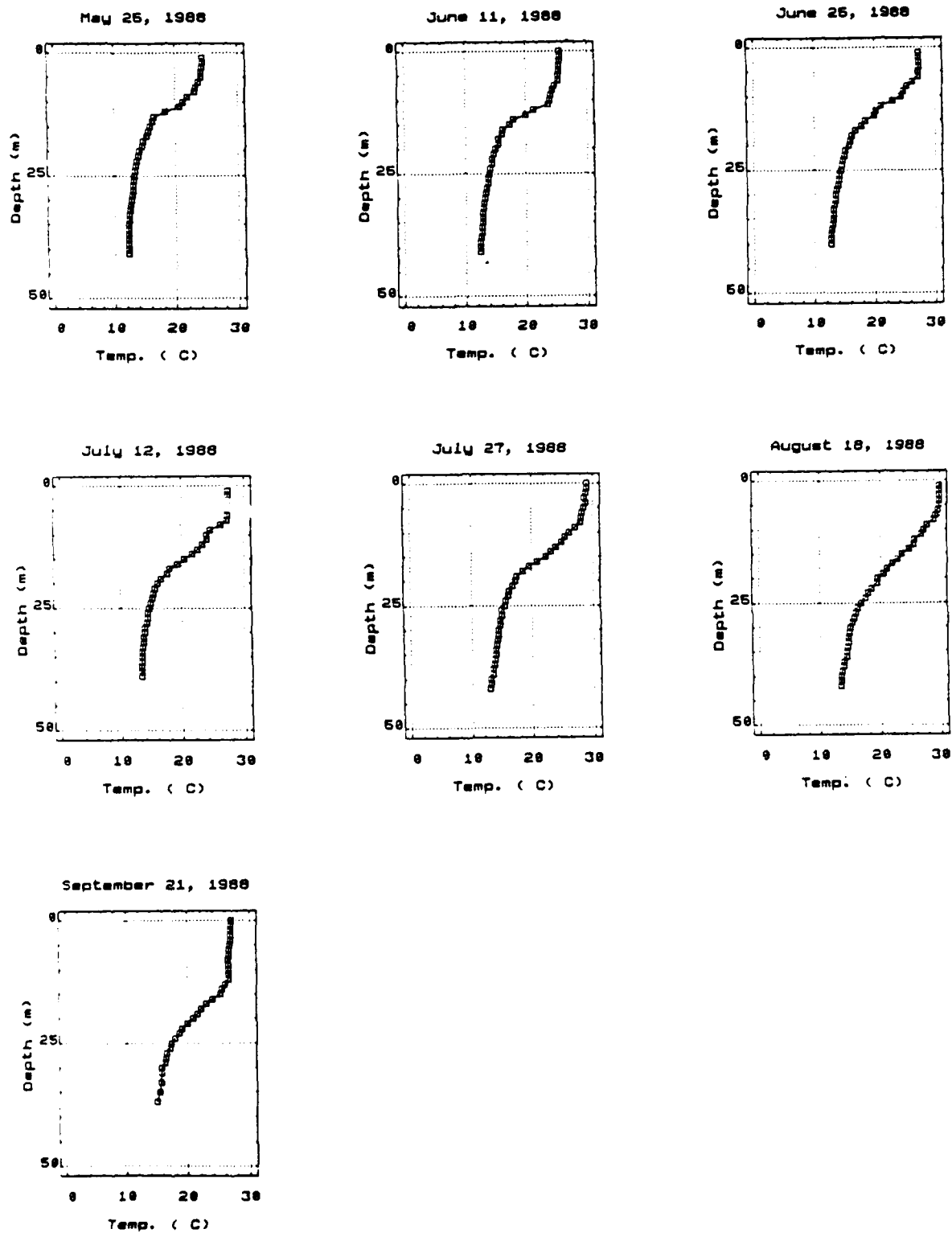
Figure C116. Canyon Lake, temperature profiles on 9/19/88
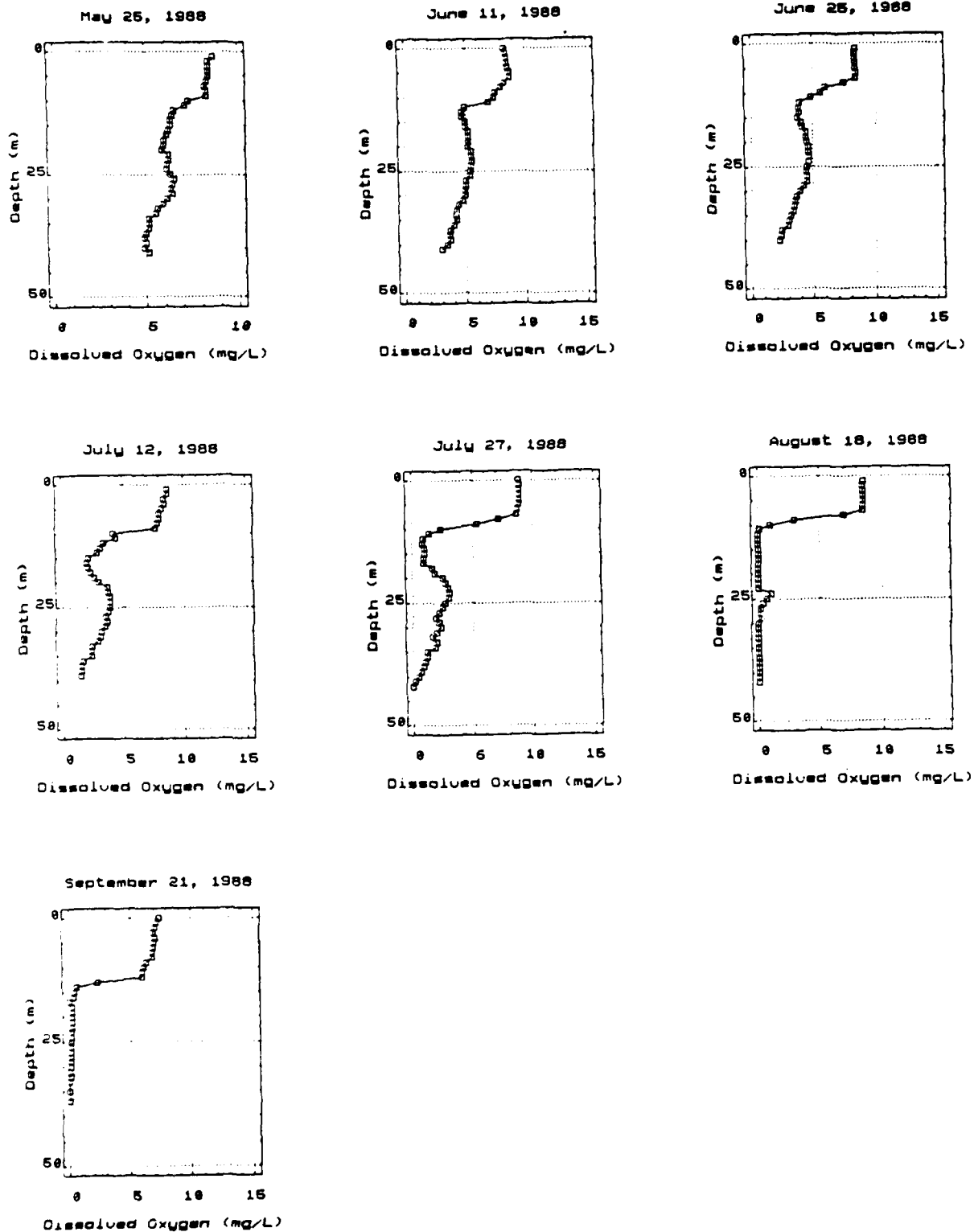
Figure C117. Canyon Lake, DO profiles on 9/19/88

CANYON TAILWATER
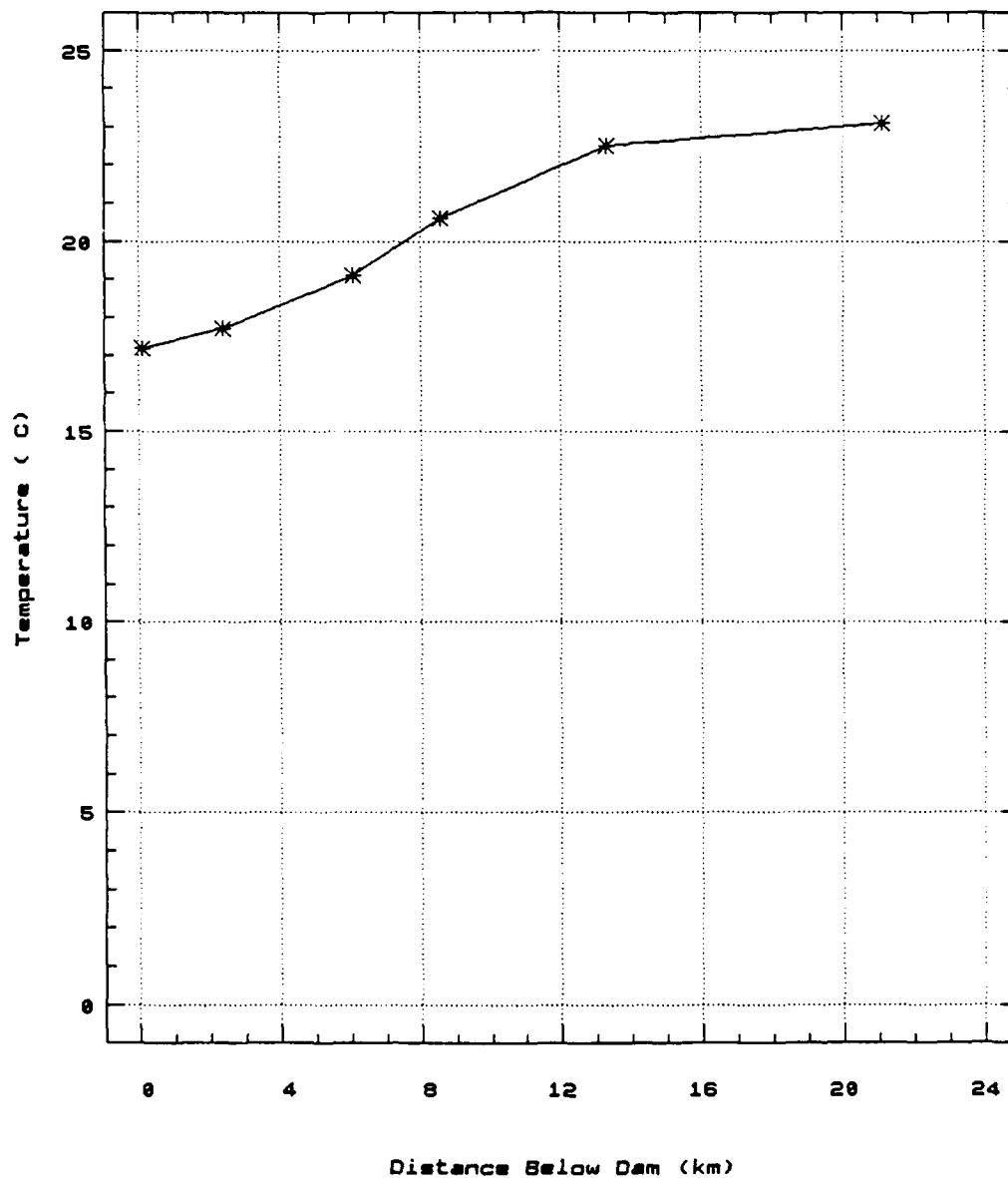
September 1988

Figure C118. Canyon Lake tailwater, temperature
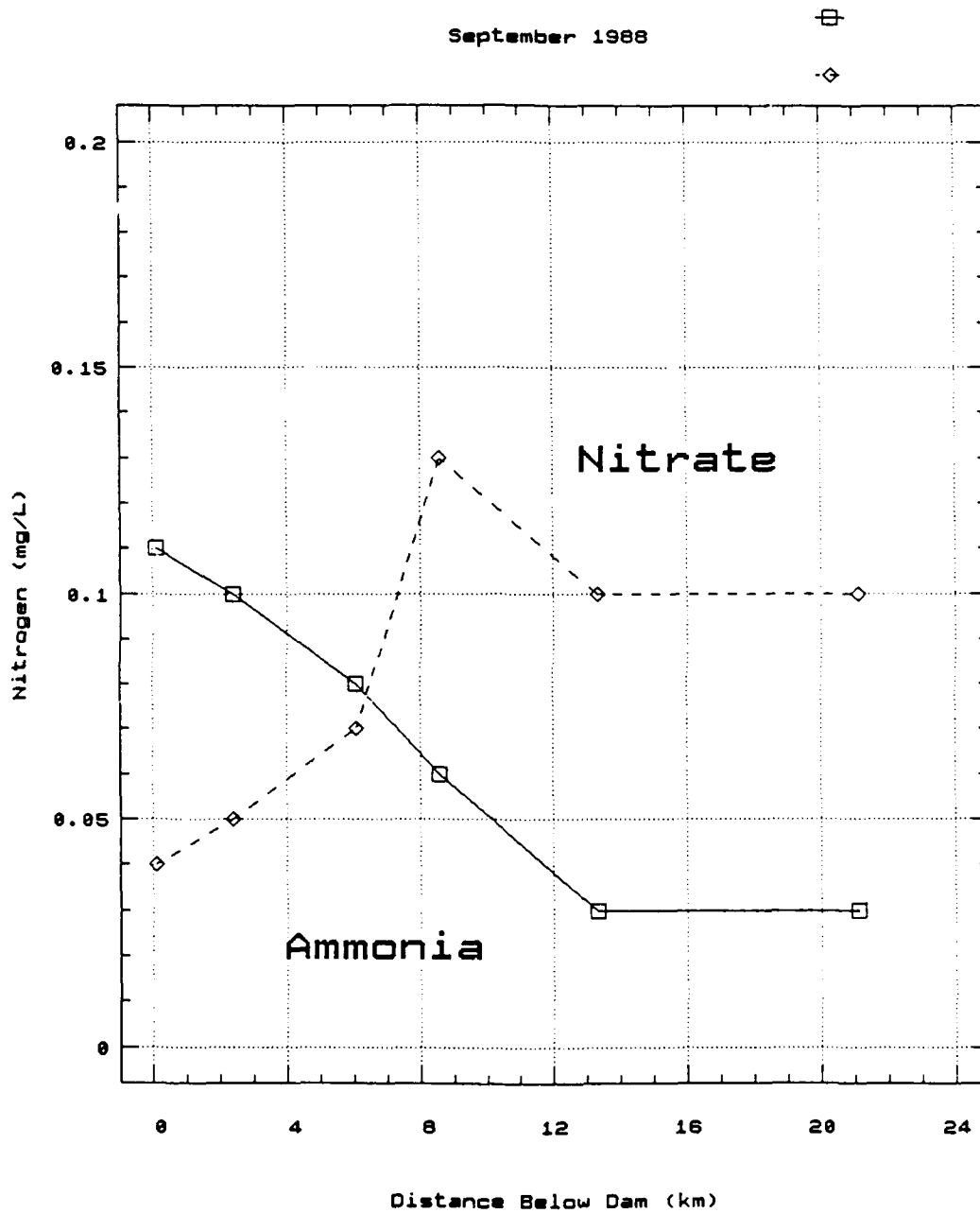versus distance below dam on 9/19/88

CANYON TAILWATER
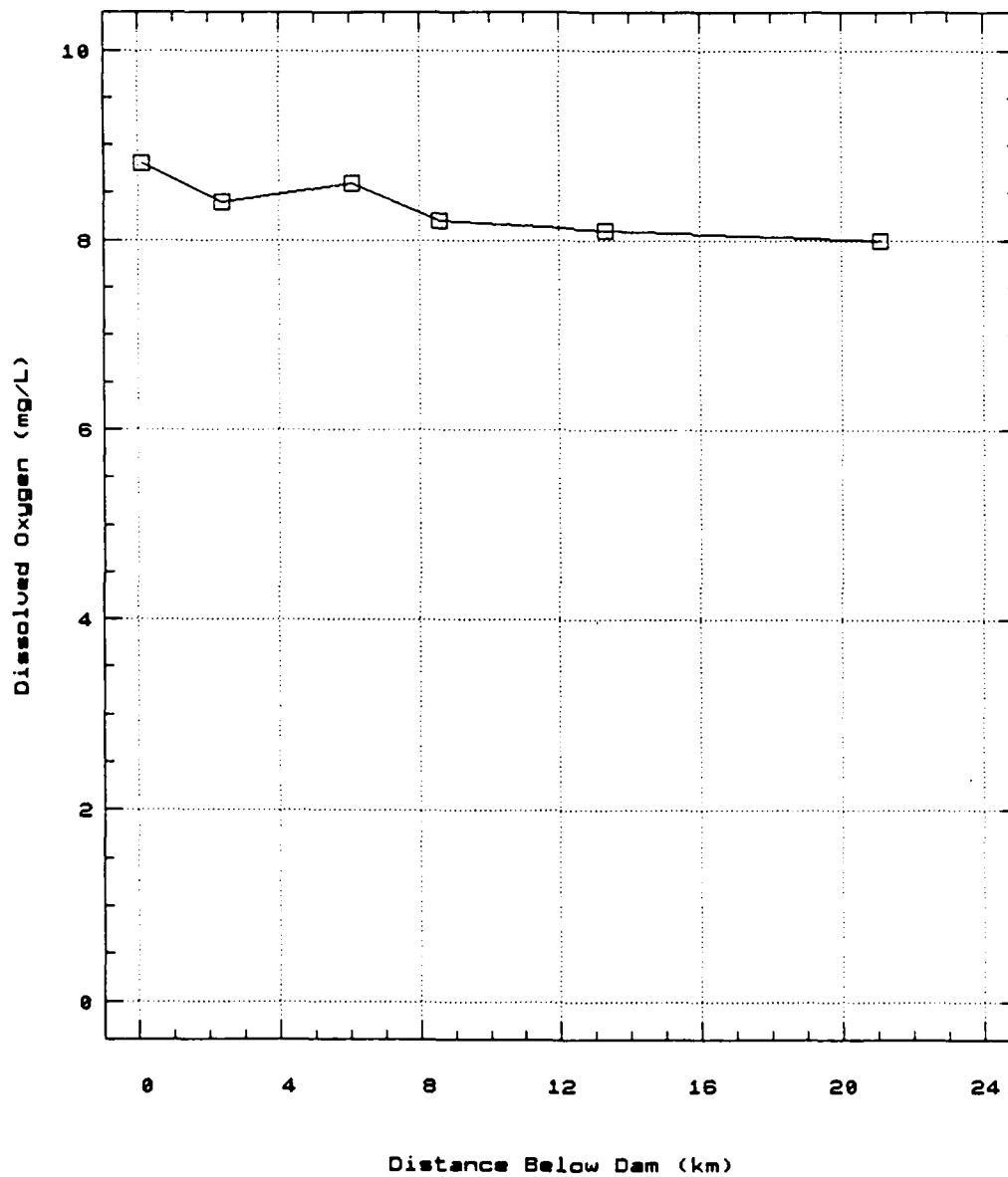
September 1988

Figure C119. Canyon Lake tailwater, DO versus
distance below dam or 9/19/88

CANYON TAILWATER
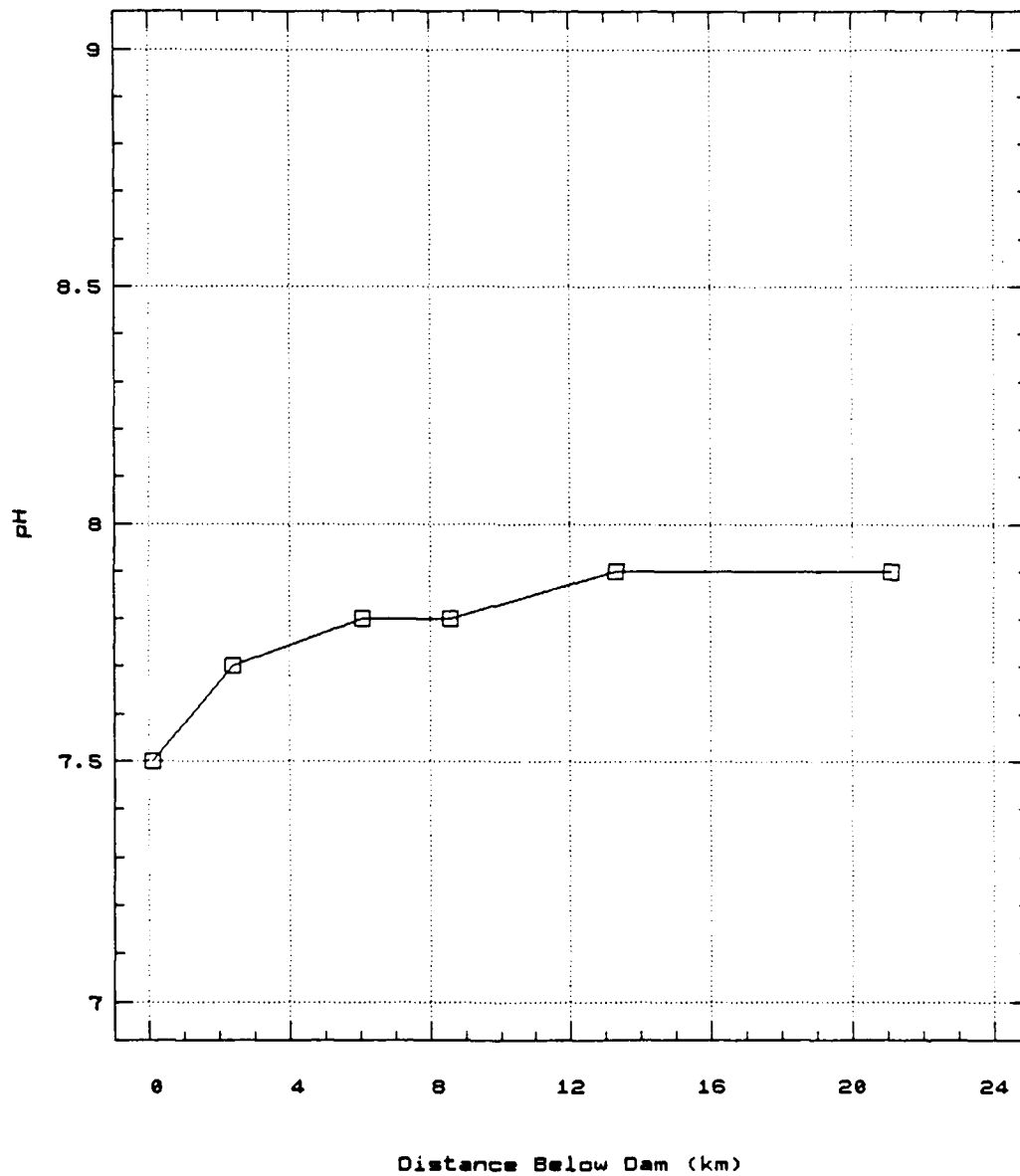
September 1988

Figure C120. Canyon Lake tailwater, pH versus distance below dam on 9/19/88

CANYON TAILWATER
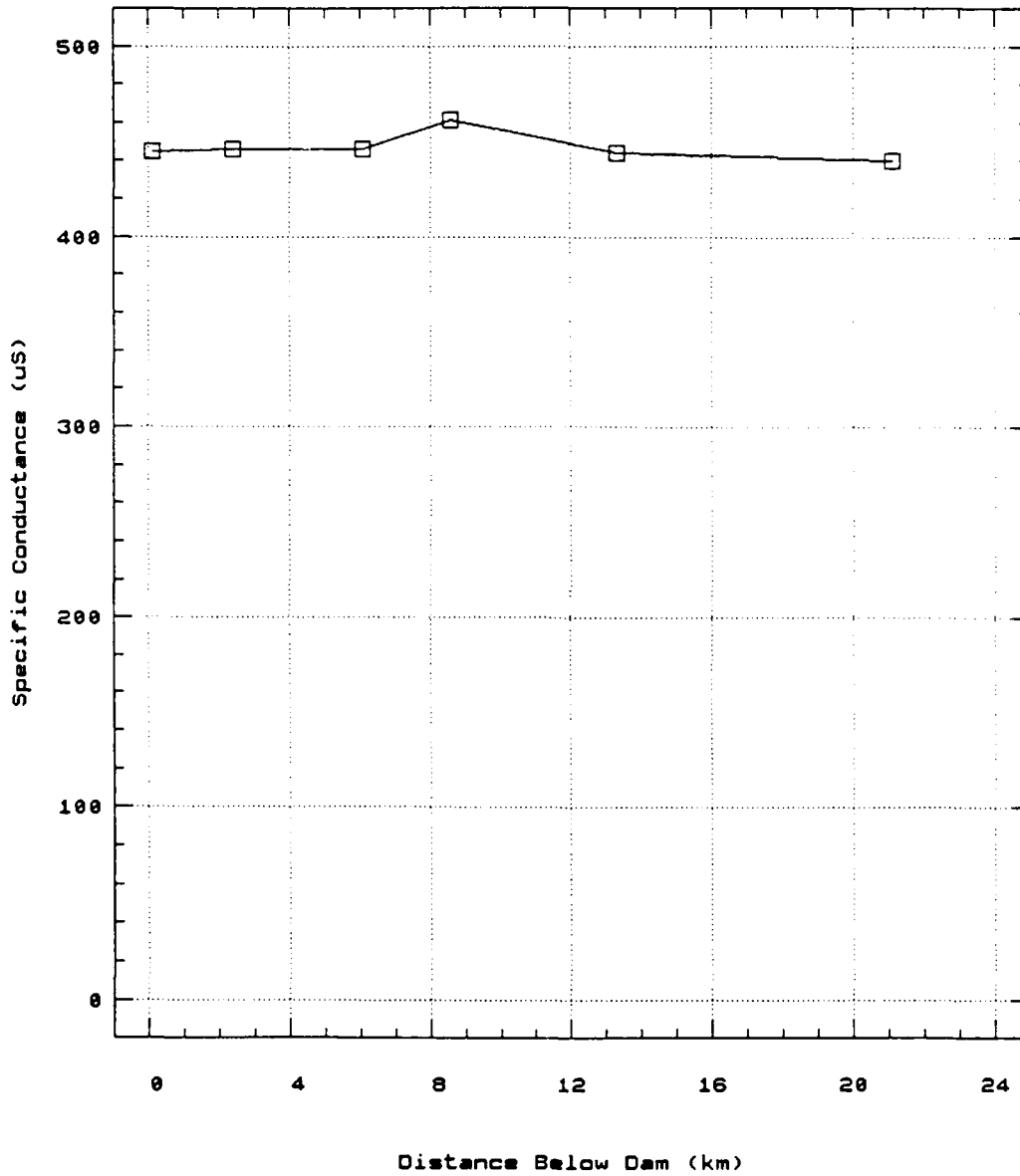
September 1988

Figure C121. Canyon Lake tailwater, specific
conductance versus distance below dam on
9/19/88

CANYON TAILWATER

September 1988

Figure C122. Canyon Lake tailwater, ammonia
nitrogen and nitrate nitrogen versus distance
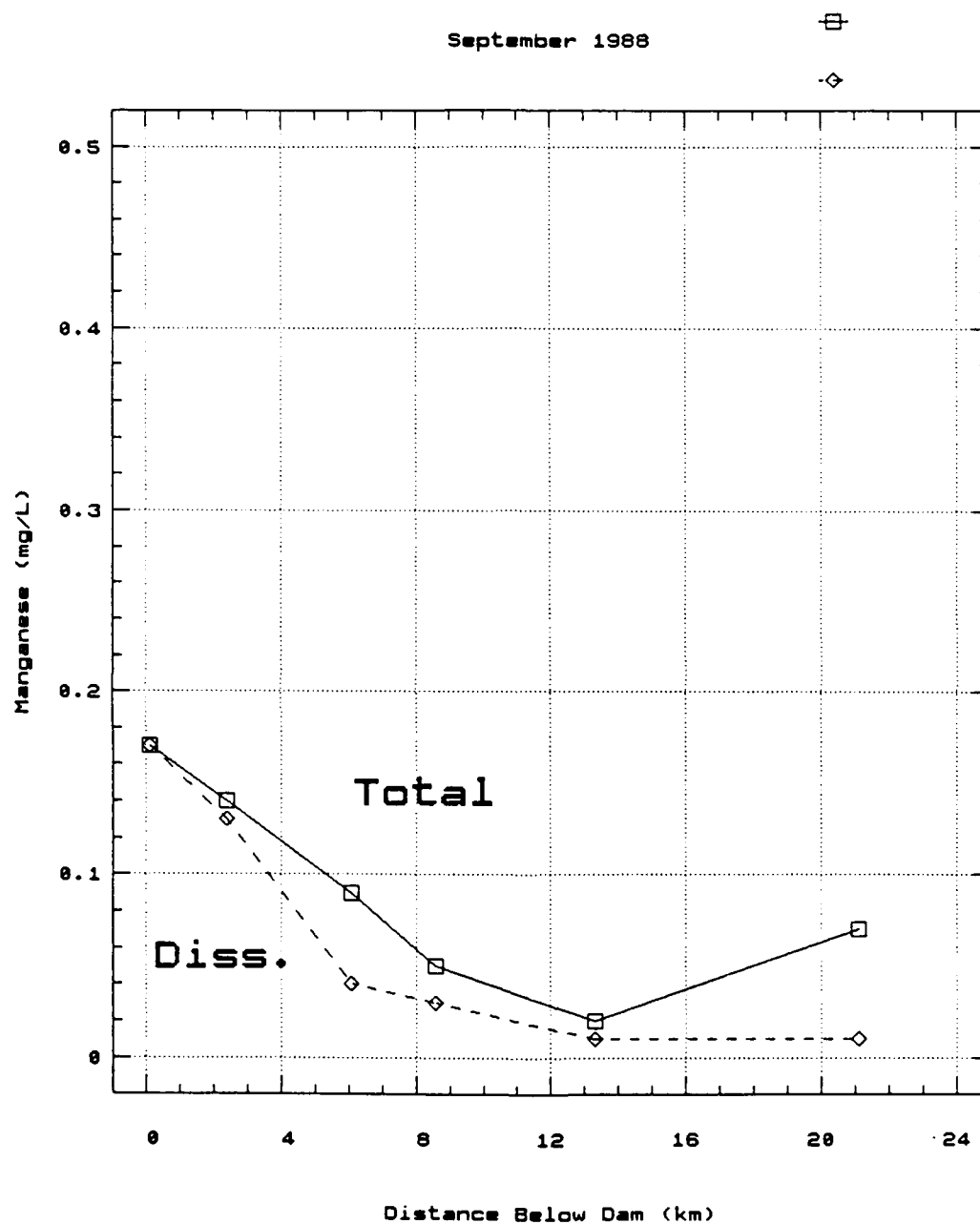below dam on 9/19/88

CANYON TAILWATER

September 1988

Figure C123. Canyon Lake tailwater total and dissolved manganese versus distance below dam on 9/19/88
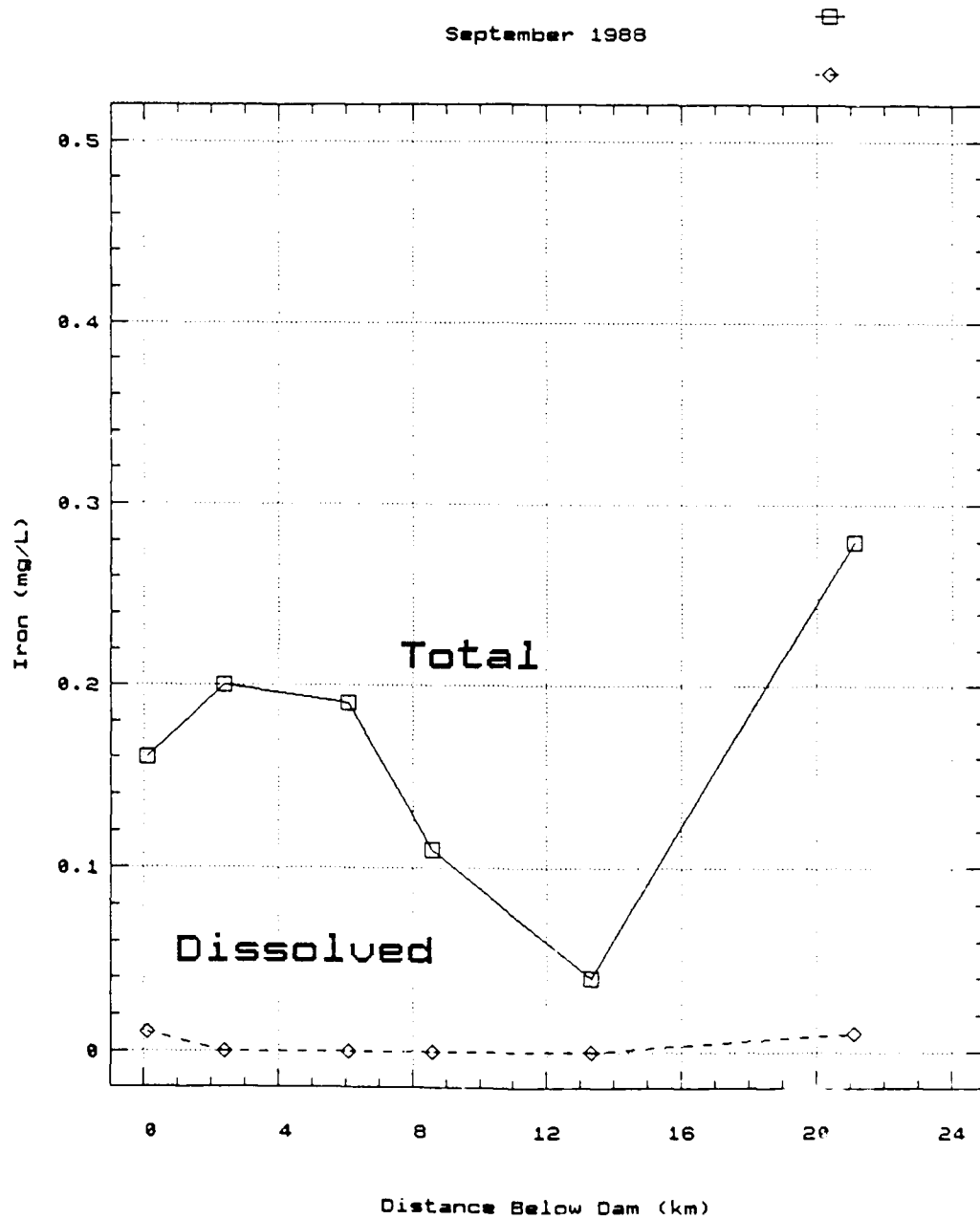
CANYON TAILWATER

September 1988

Figure C124.   Canyon Lake tailwater, total and
dissolved iron versus distance below dam on
9/19/88
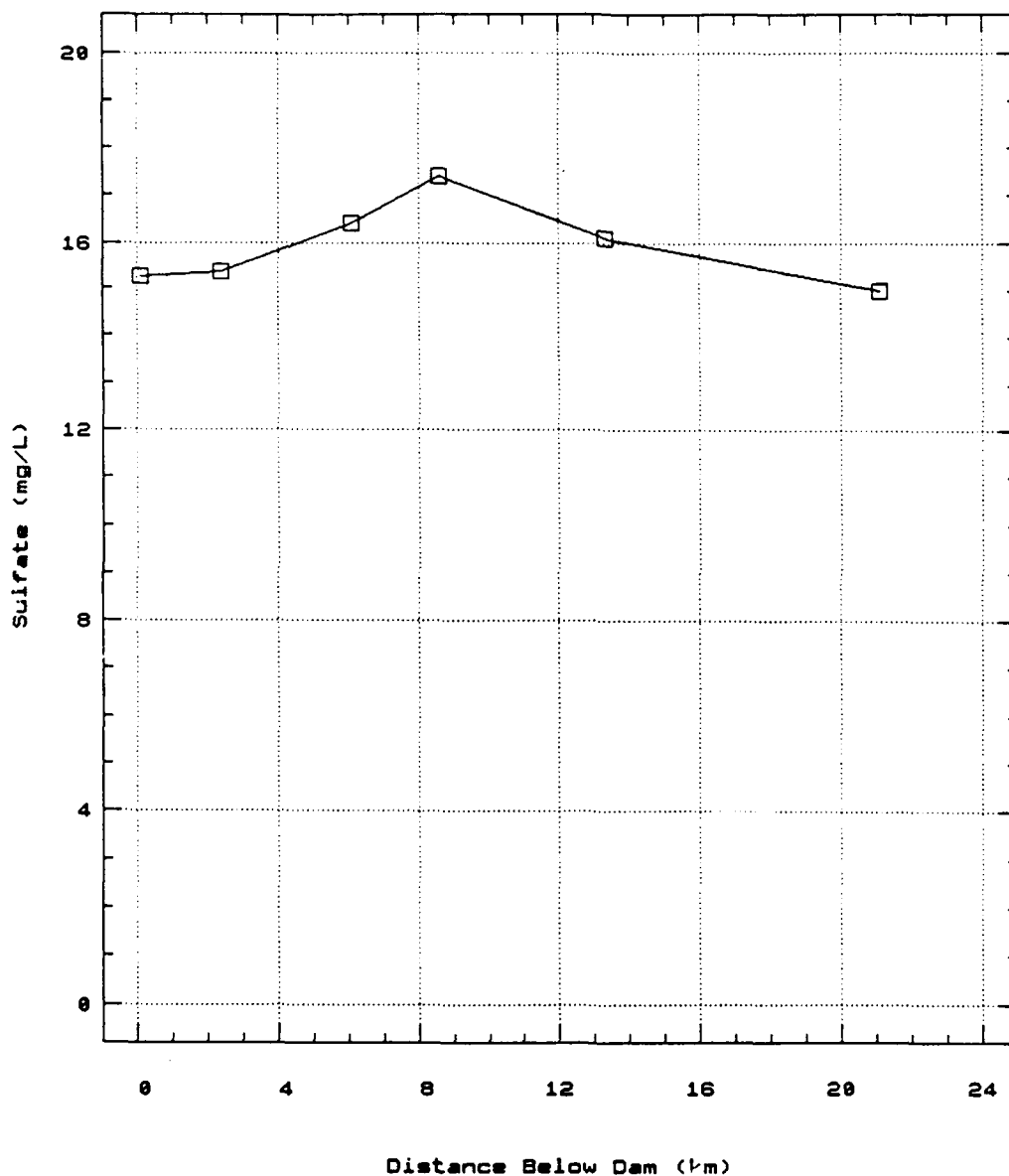
CANYON TAILWATER

September 1988

Figure C125.   Canyon Lake tailwater, sulfate
versus distance below dam on 9/19/88